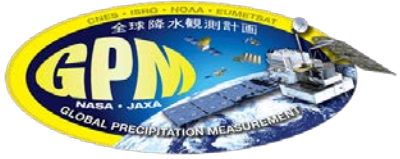




GPM Orbital Maintenance Planning and Operations in Low Solar Activity Environment

Scott Patano, Ralph Myers, and Jorge Aviles
Omitron, Inc. and KBRwyle



Global **P**recipitation **M**easurement Project



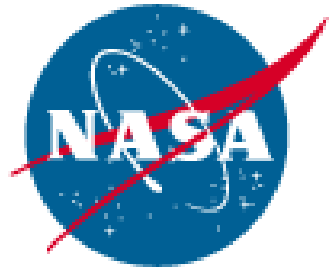
Global **P**recipitation **M**easurement Project

A World-Wide Multi-Agency Effort Led by



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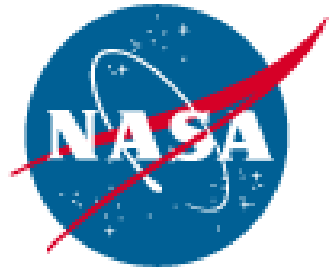
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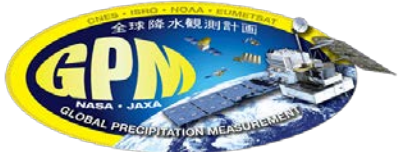




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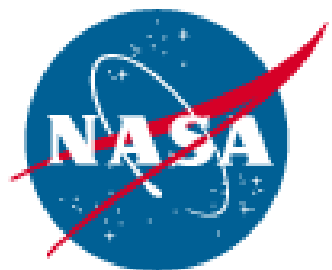
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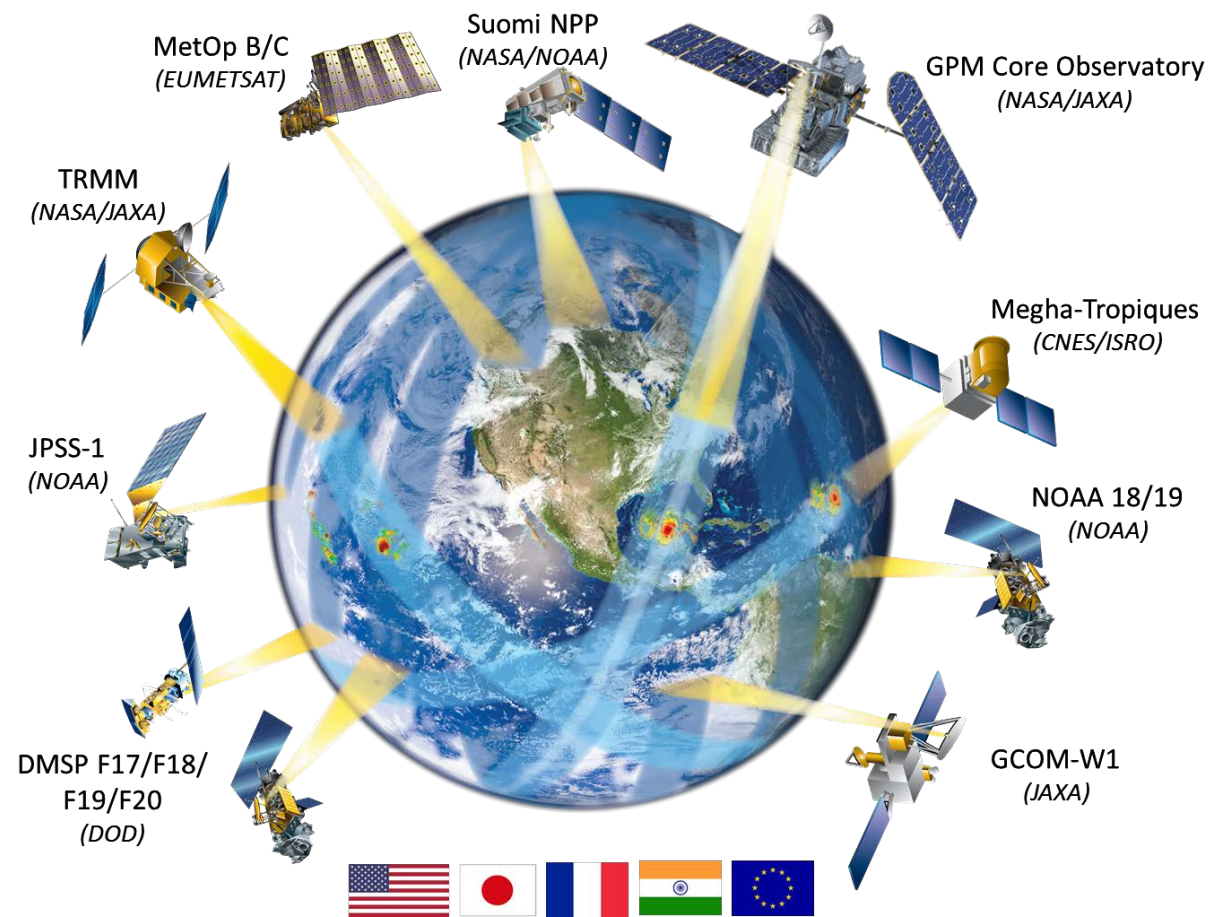
Global **P**recipitation **M**easurement Project

A World-Wide Multi-Agency Effort Led by



to Provide Comprehensive Measurement of
Precipitation and the Global Water Cycle

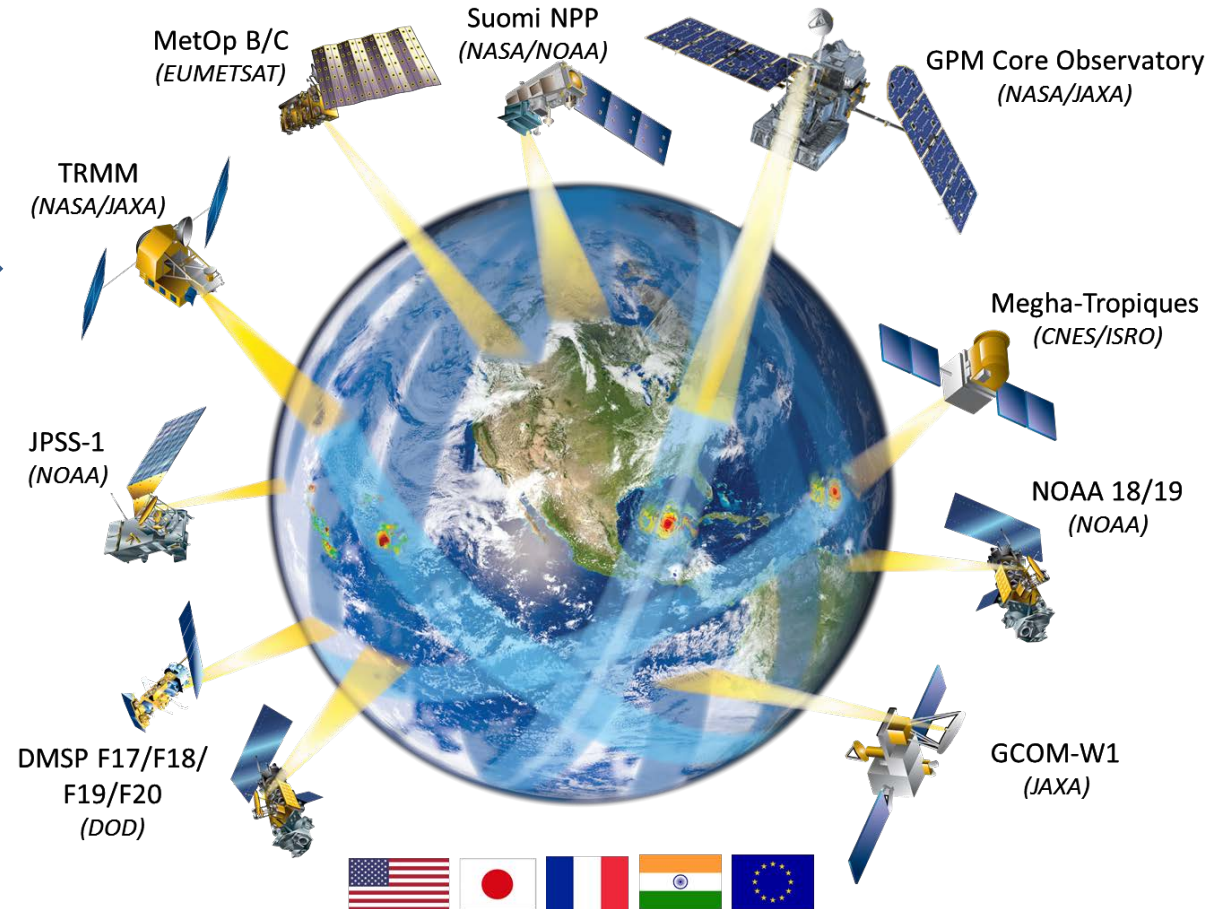
GPM Constellation Status



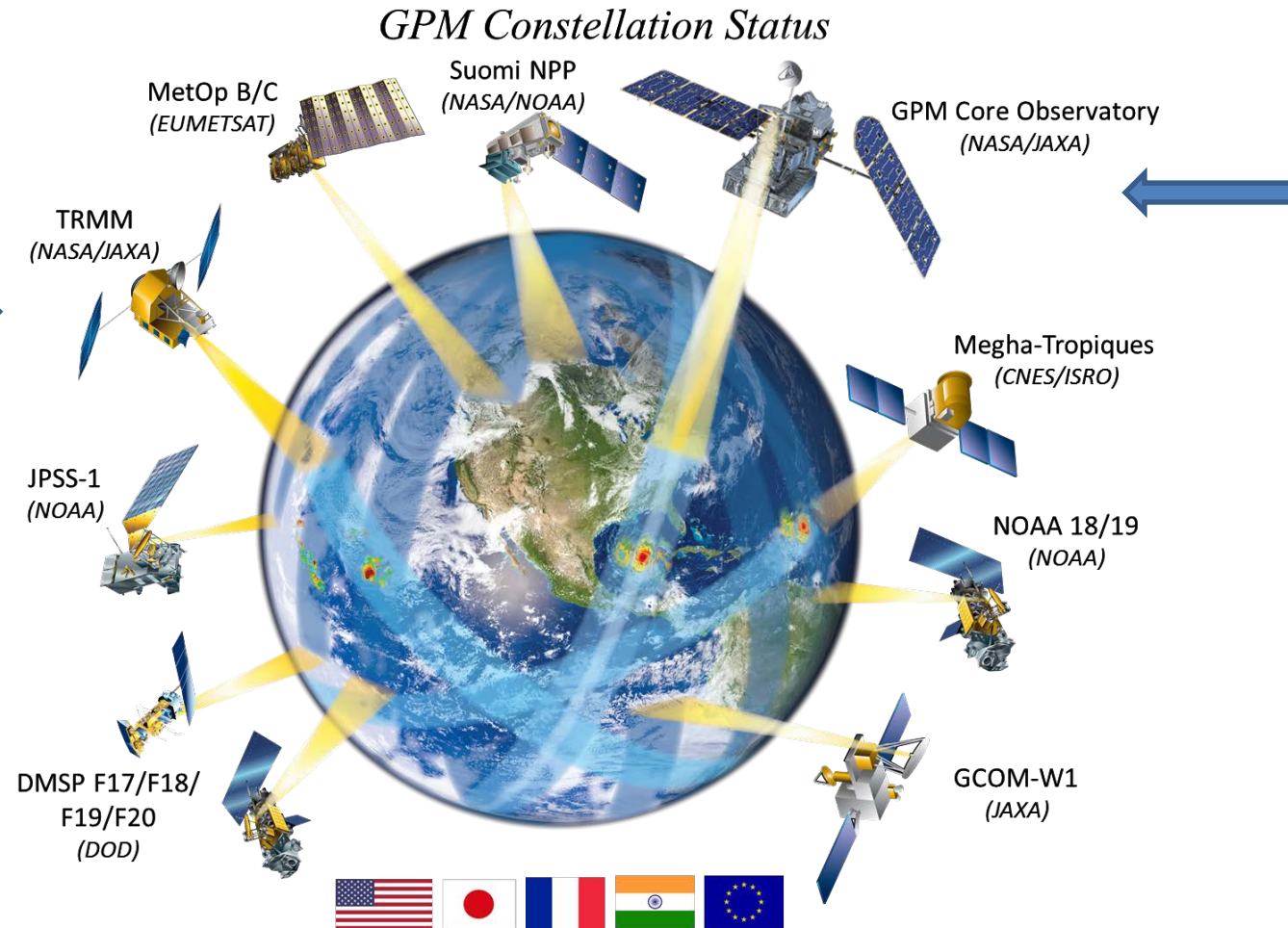
Building on
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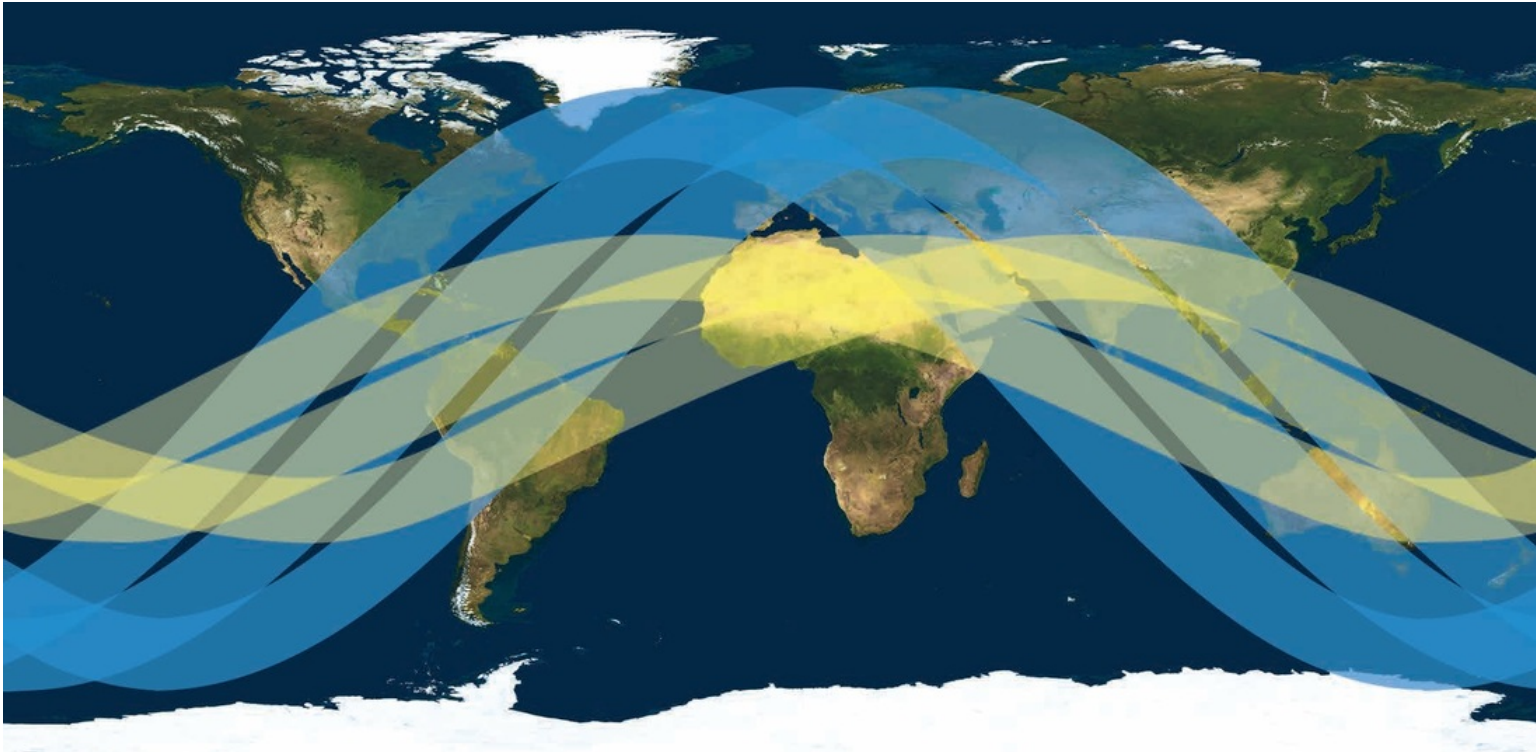


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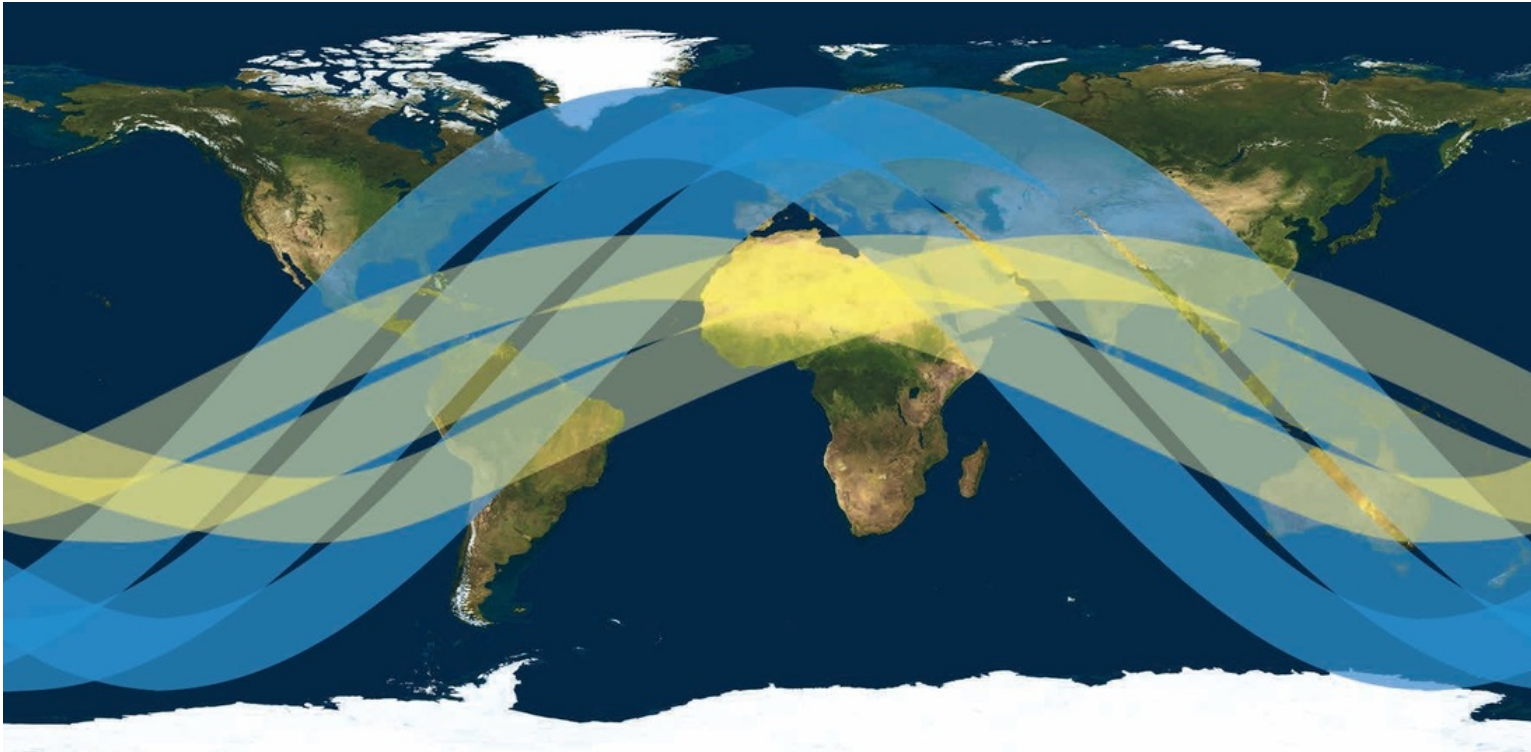


...the “Core”
Observatory
functions as a
reference
standard for
measurements
from the
operational
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TRMM (yellow) focused on tropical rainfall with an inclination of 35°



TRMM (yellow) focused on tropical rainfall with an inclination of 35°



GPM "Core" (blue) greatly expands coverage with an inclination of 65°



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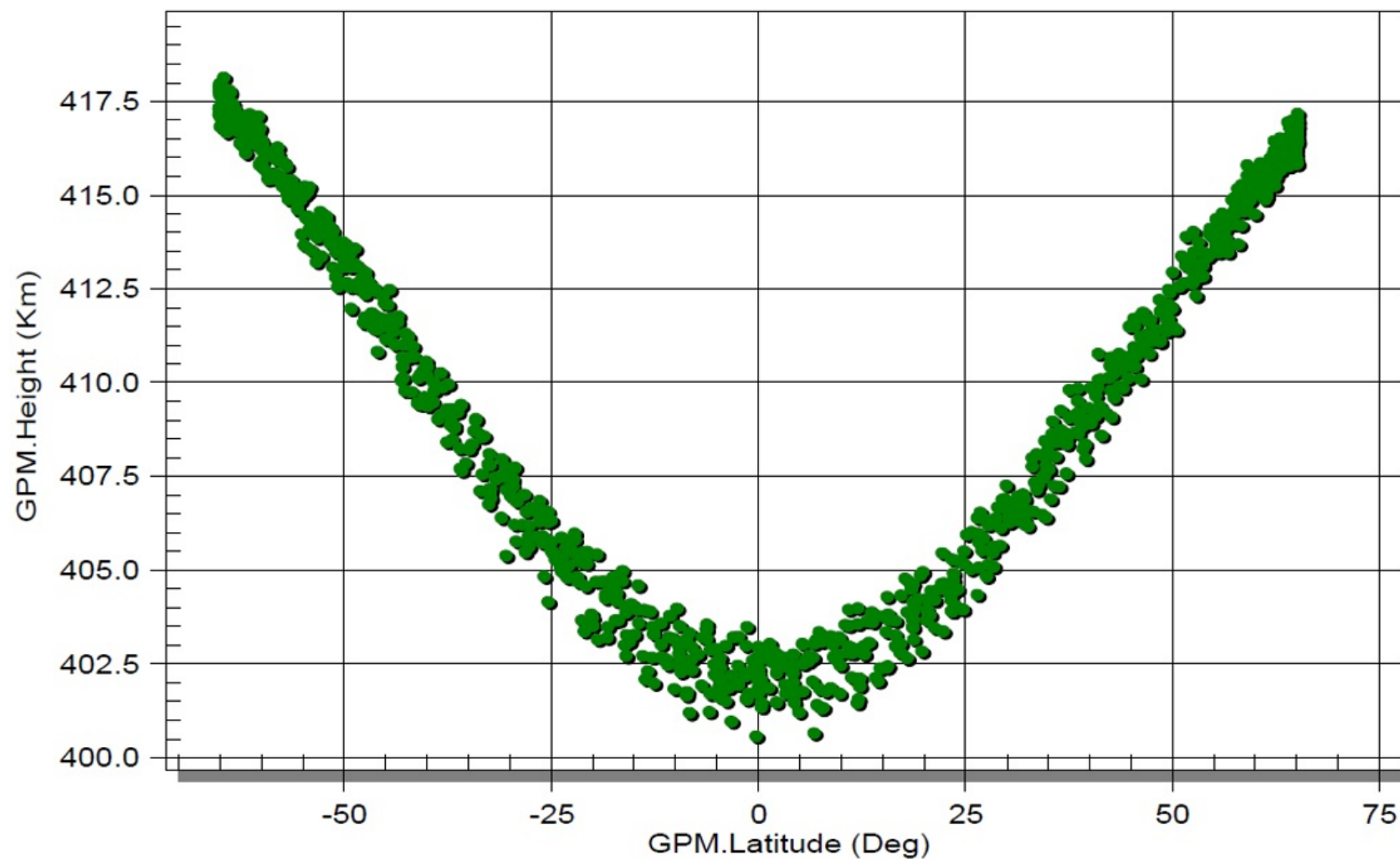


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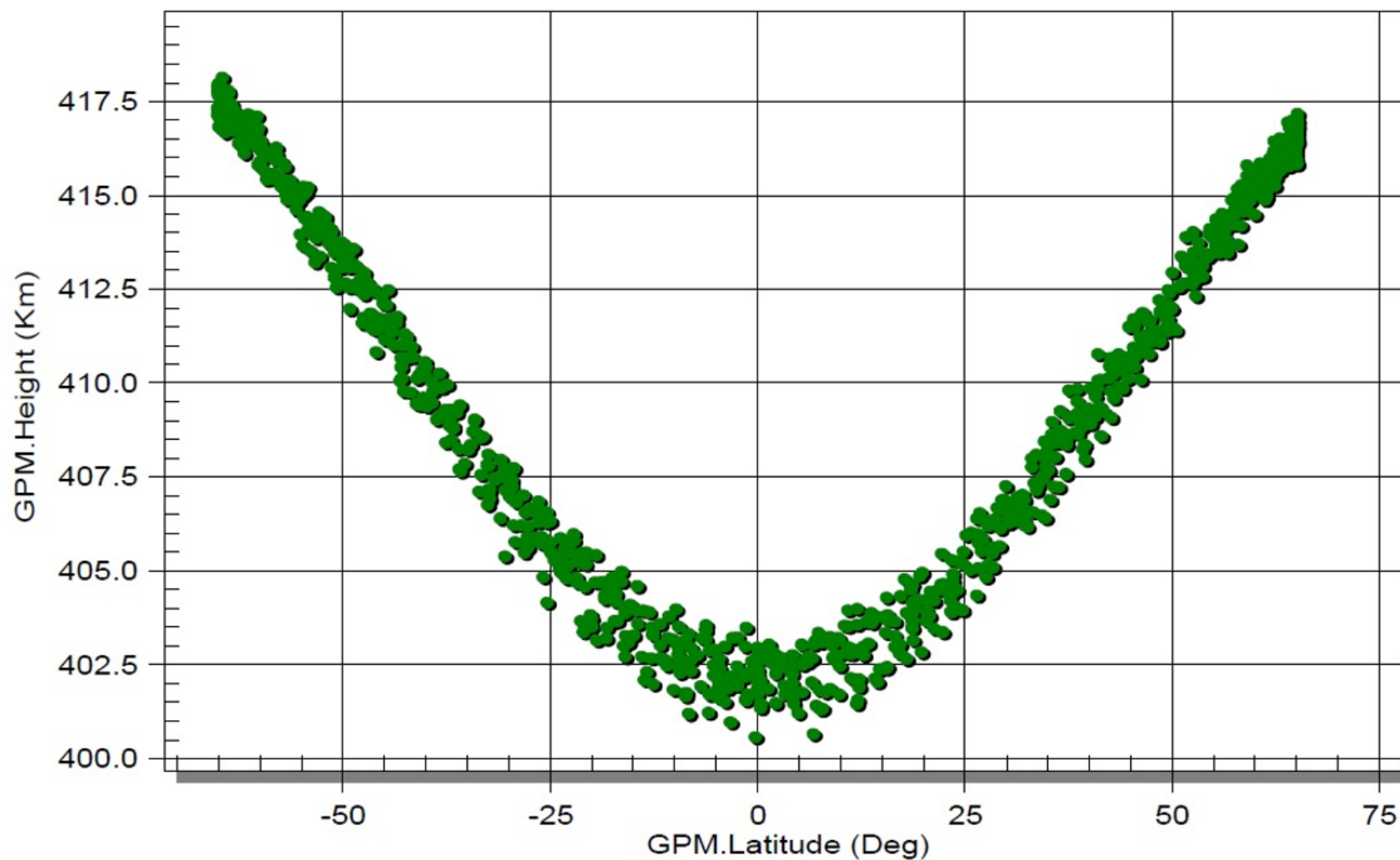
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Required tolerances
in SMA (± 1.0 km)
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Geodetic HGT limits
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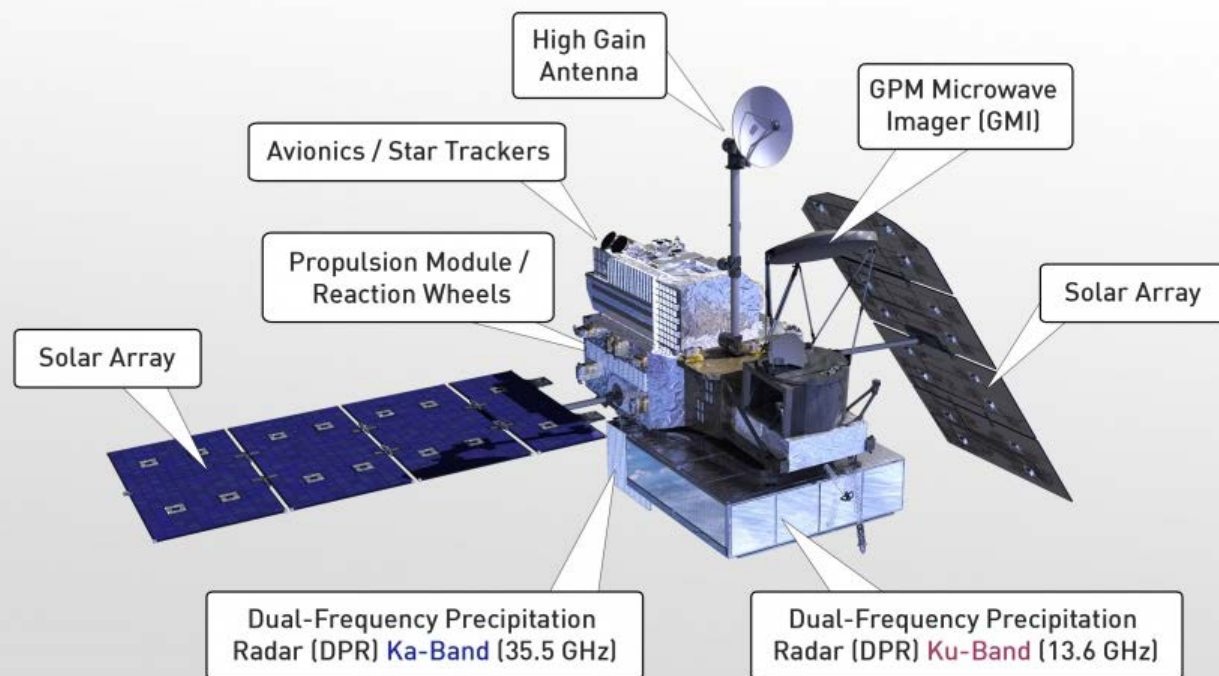
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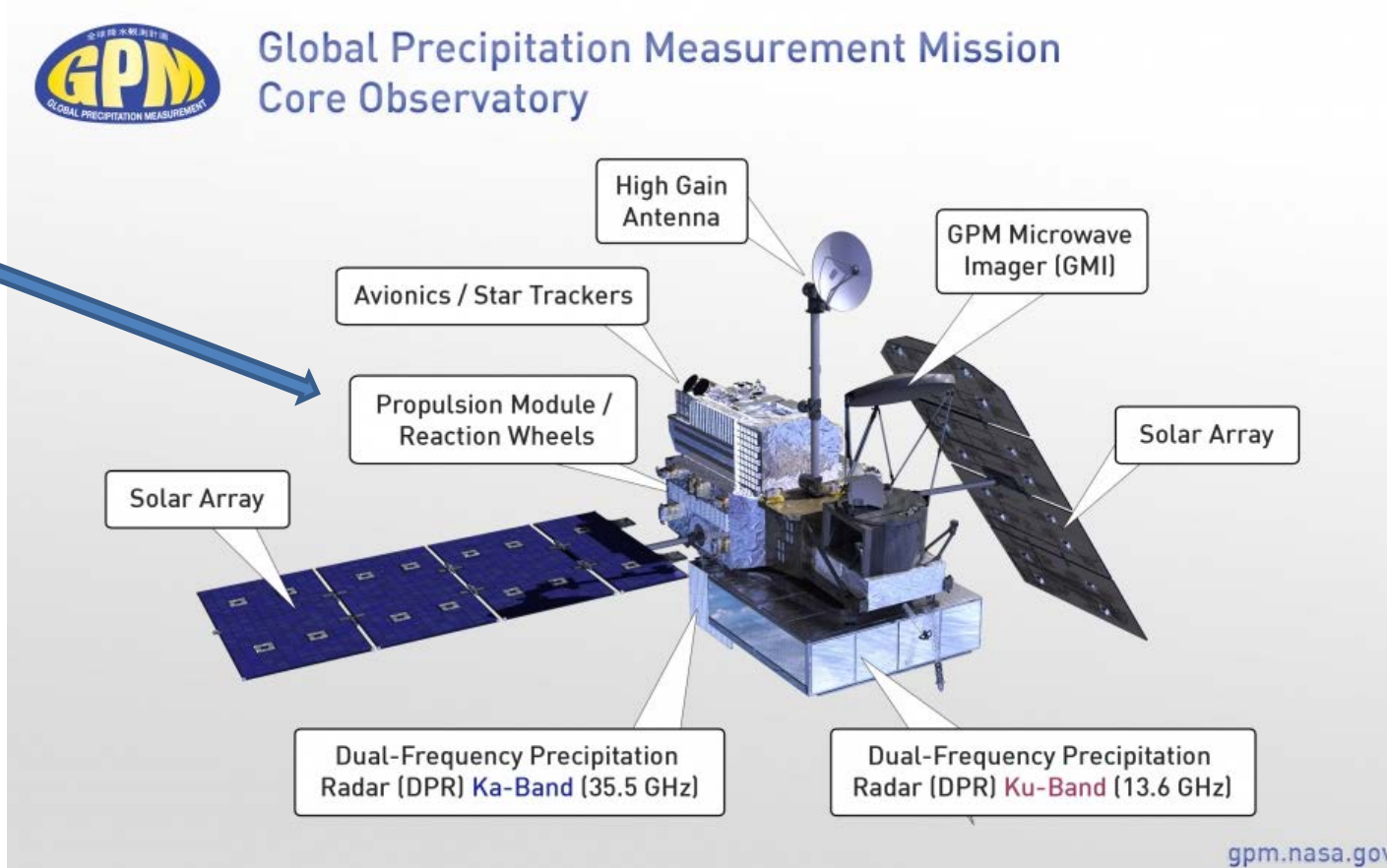




Global Precipitation Measurement Mission Core Observatory

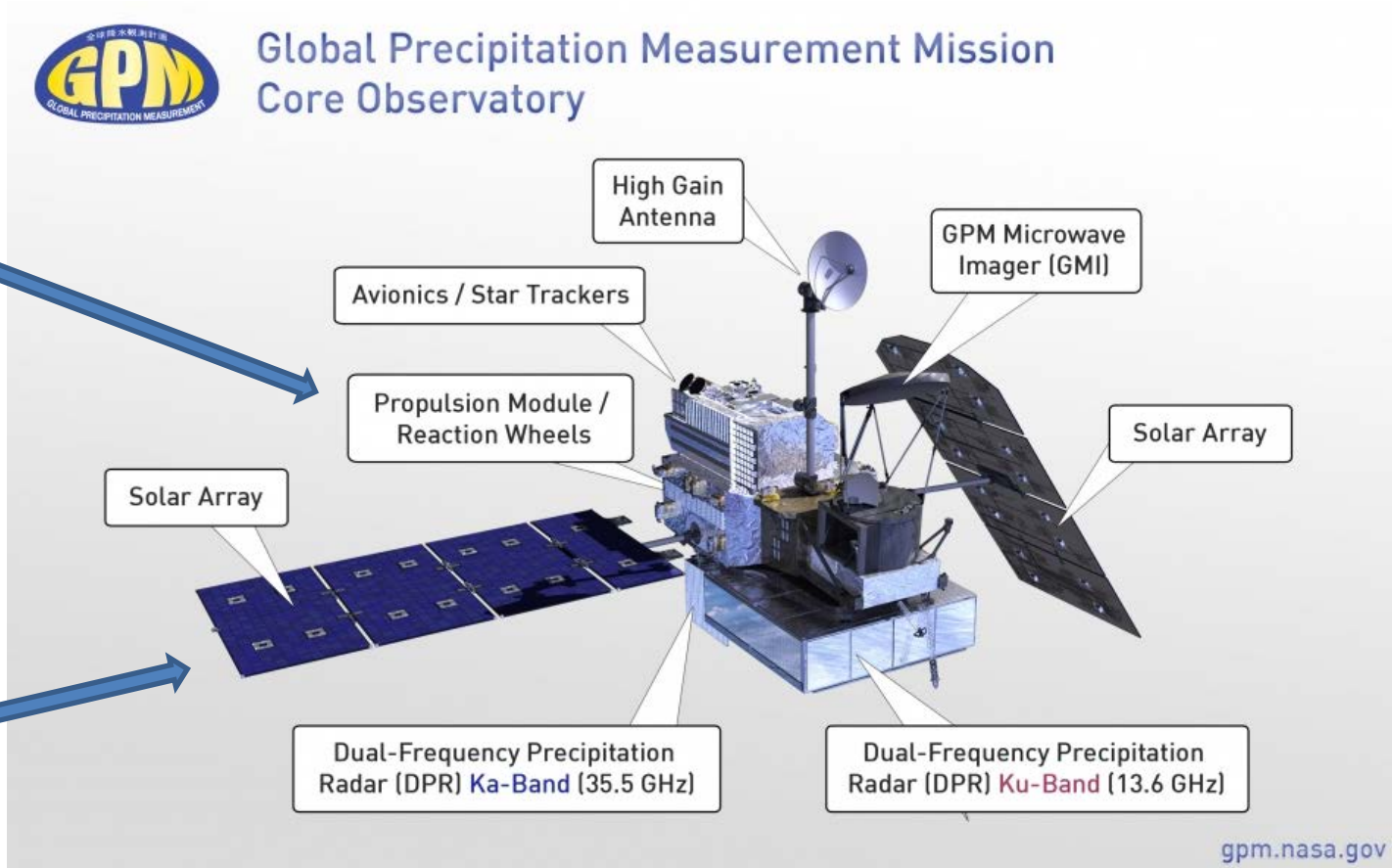


12 Thrusters
(8 Aft, 4 Fwd)
maintain orbit
and dump
reaction wheel
momentum



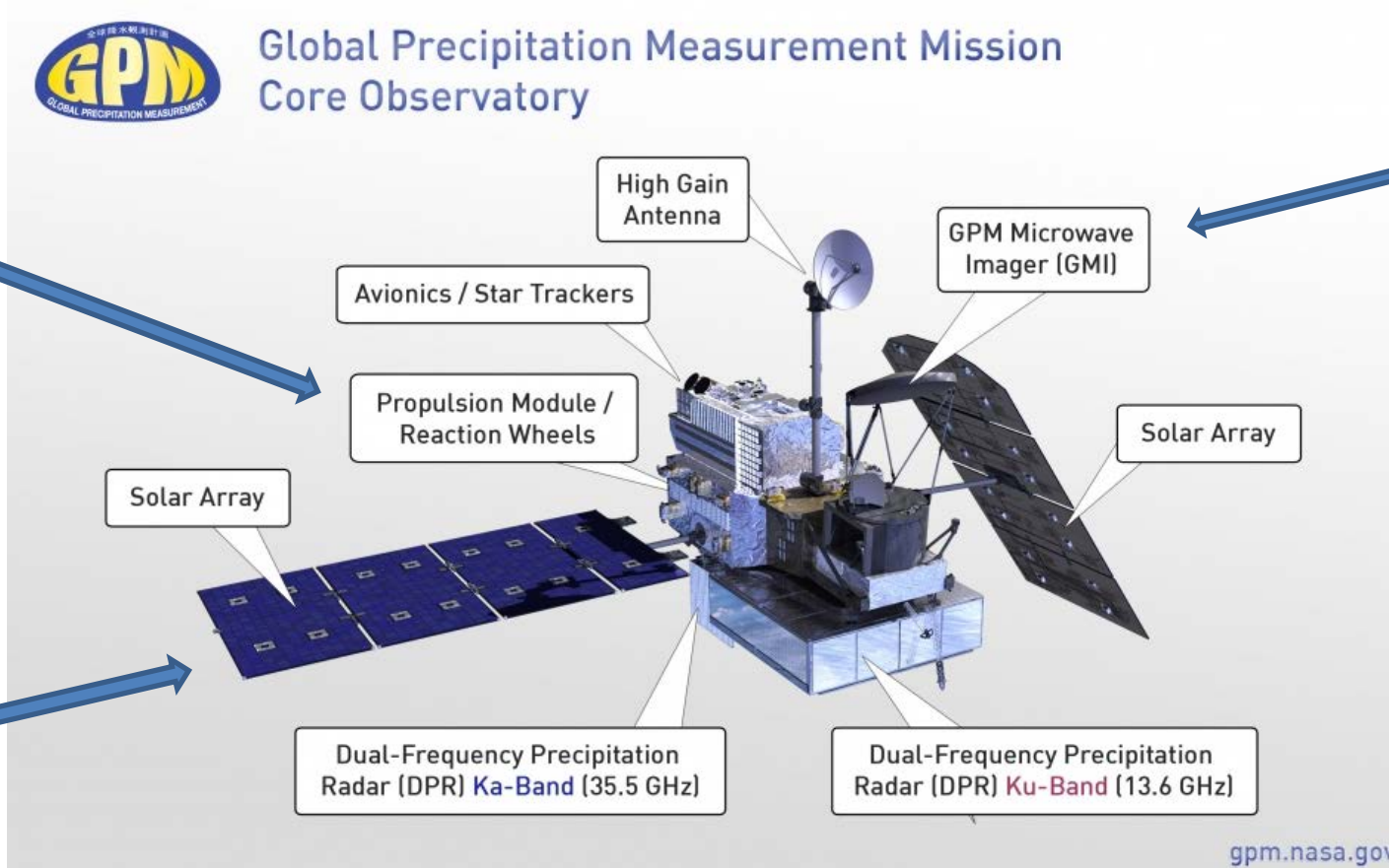
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Two solar arrays
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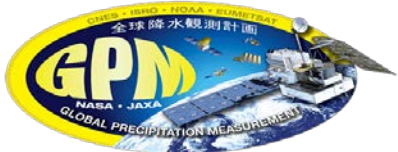


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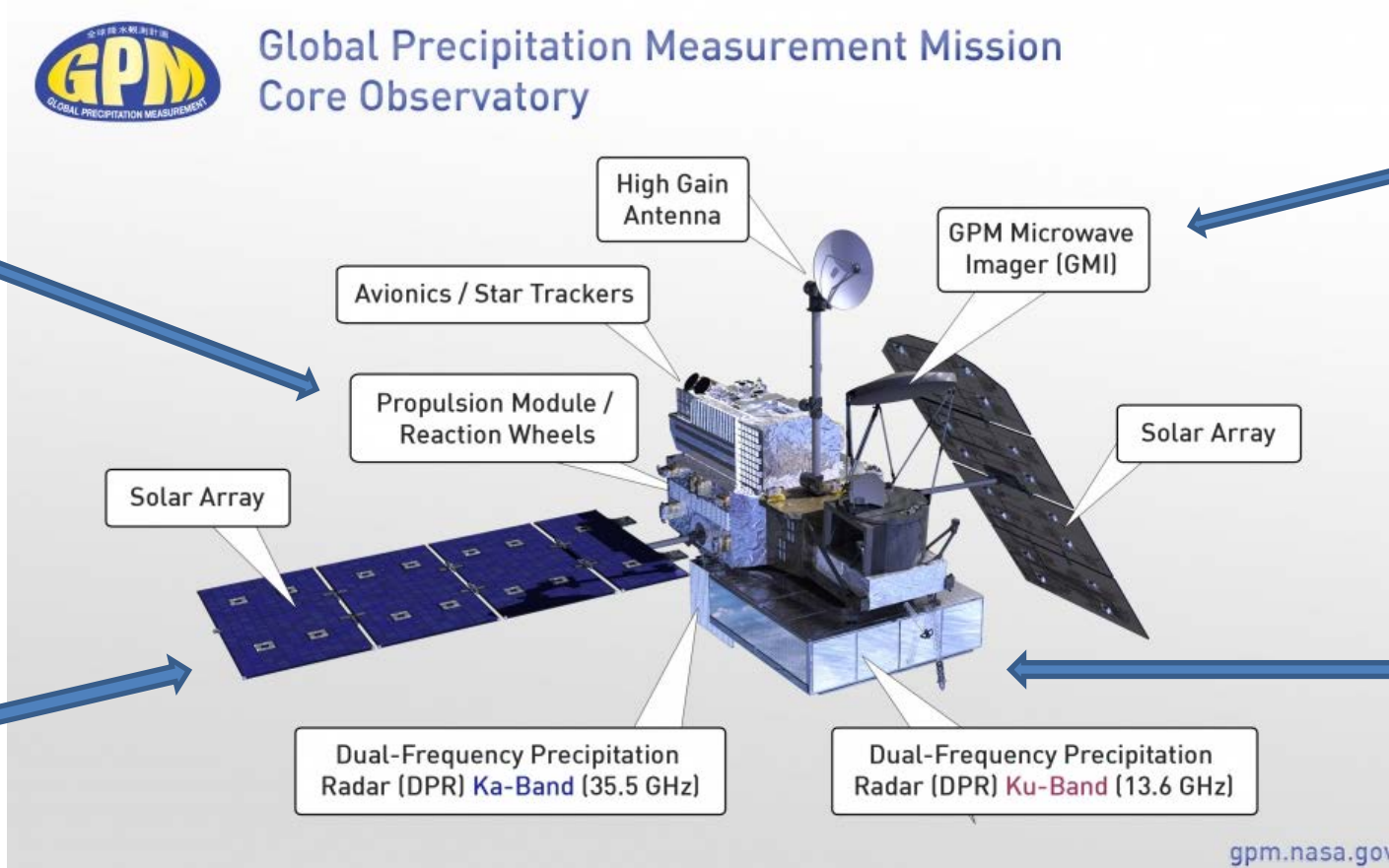


Passive GMI
(from NASA)
scans area in
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Passive GMI
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scans area in
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Active DPR
(from JAXA)
scans swath at
GPM nadir with
Ka and Ku-Band



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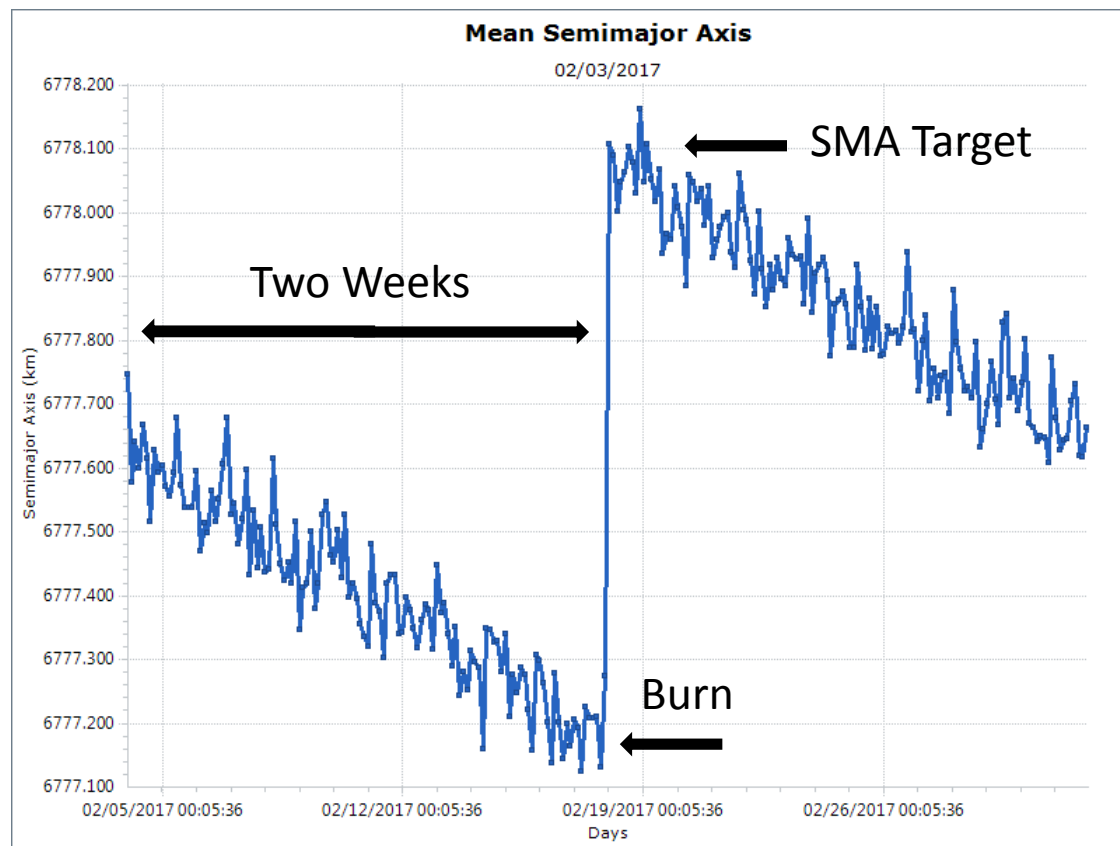


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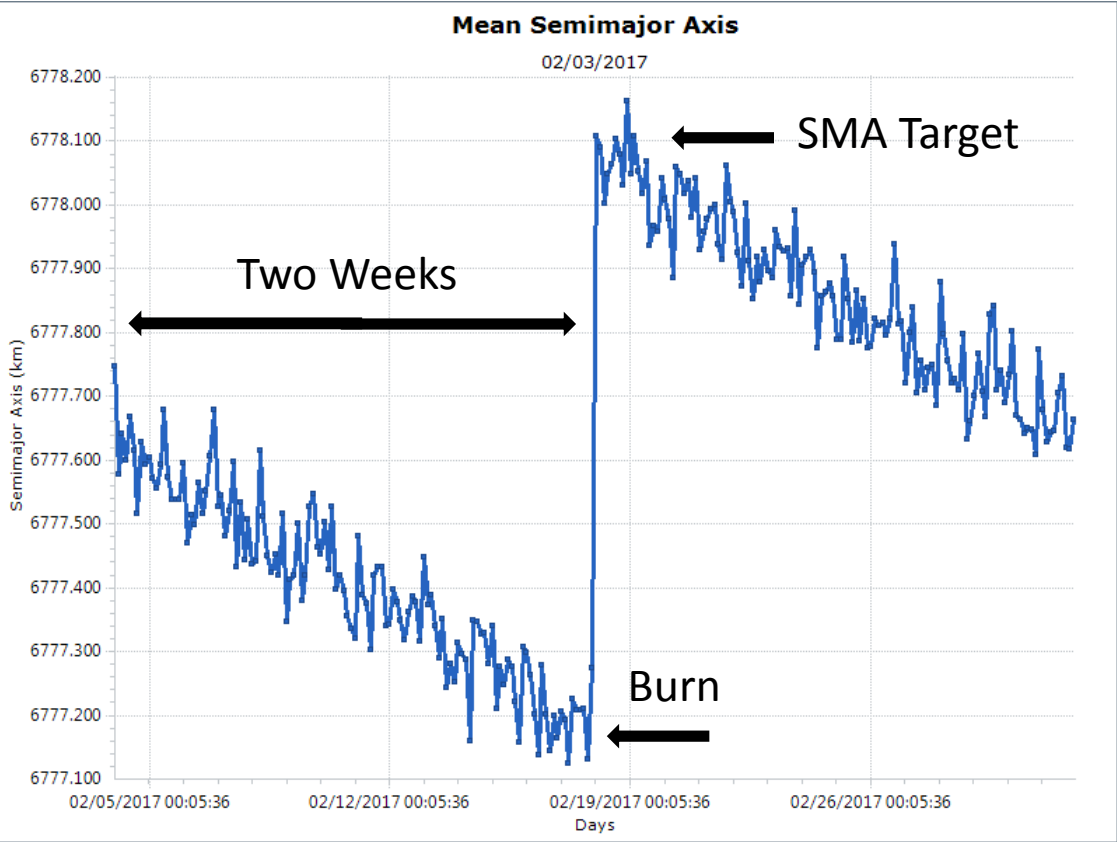


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- **Maneuvers have different “triggers” and “targets”:
Cadence, Geodetic Height (HGT), and SMA**

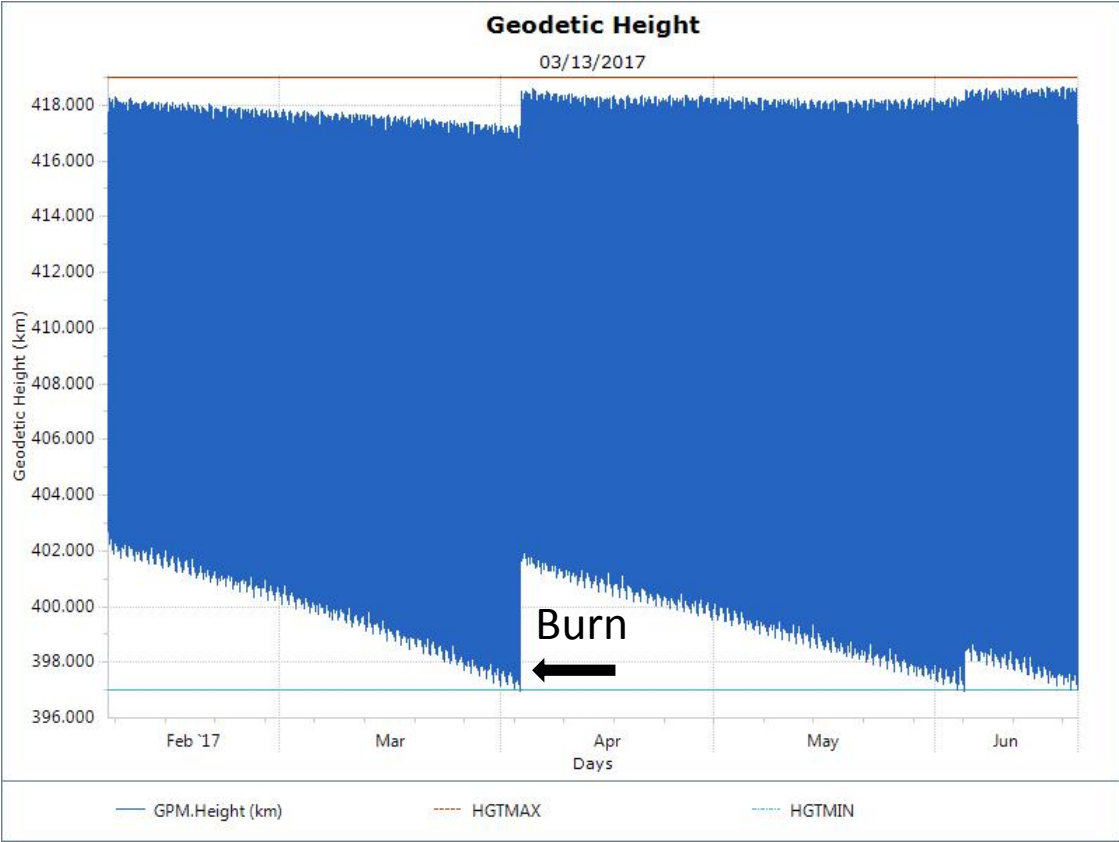
Cadence – trigger every X number of weeks to achieve higher SMA target



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Geodetic Height – maneuver at Min HGT limit to achieve higher SMA target





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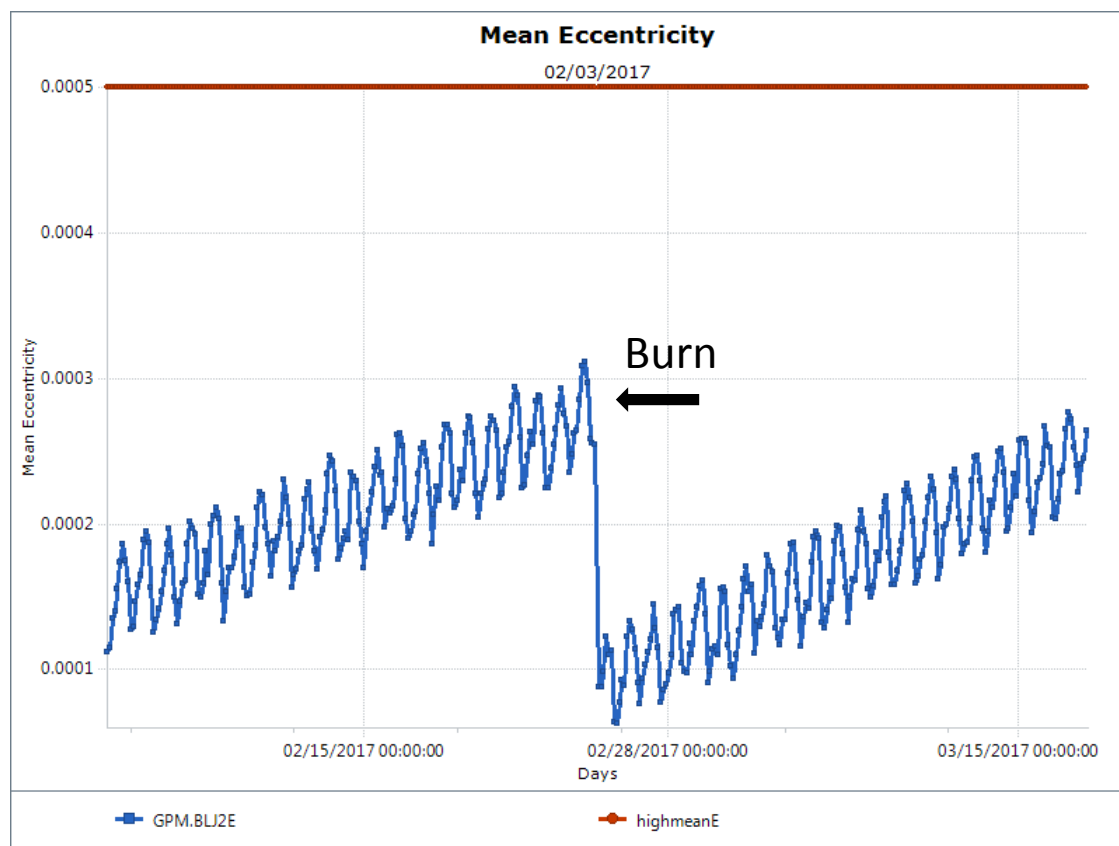
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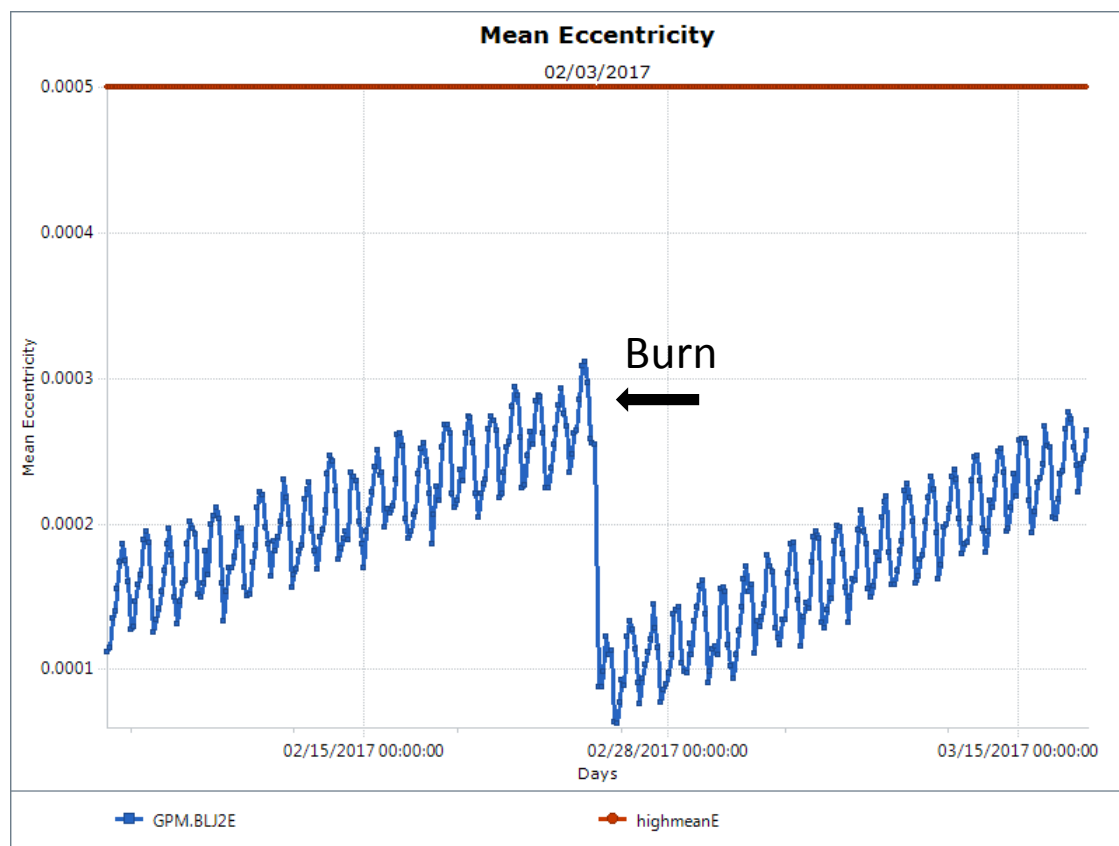
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- **Current scheme triggers a maneuver per a minimum HGT condition, targets to achieve a result in SMA, and potentially replans based on the HGT outcome**

Mean Eccentricity (ECC) – expected to be well-controlled under limit of 0.0005

- With the assumption that ECC remains well-behaved, the current targeting scheme effectively maintains the orbit

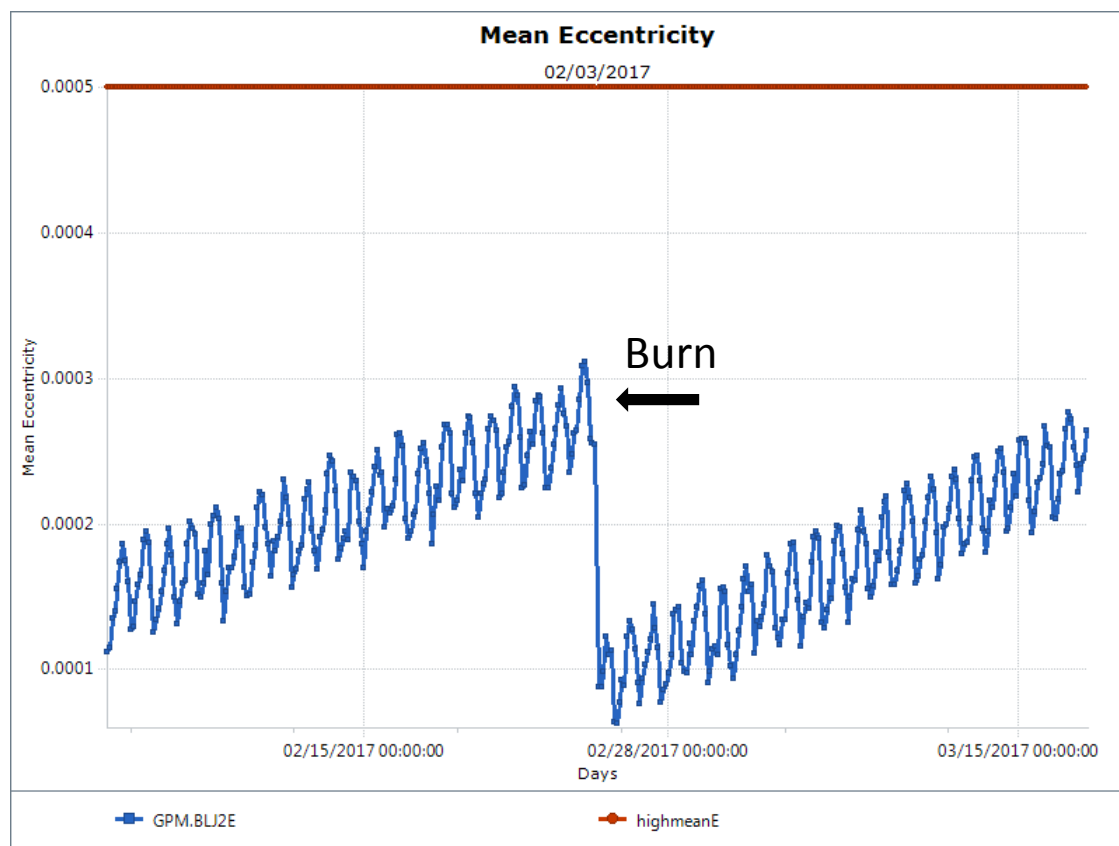


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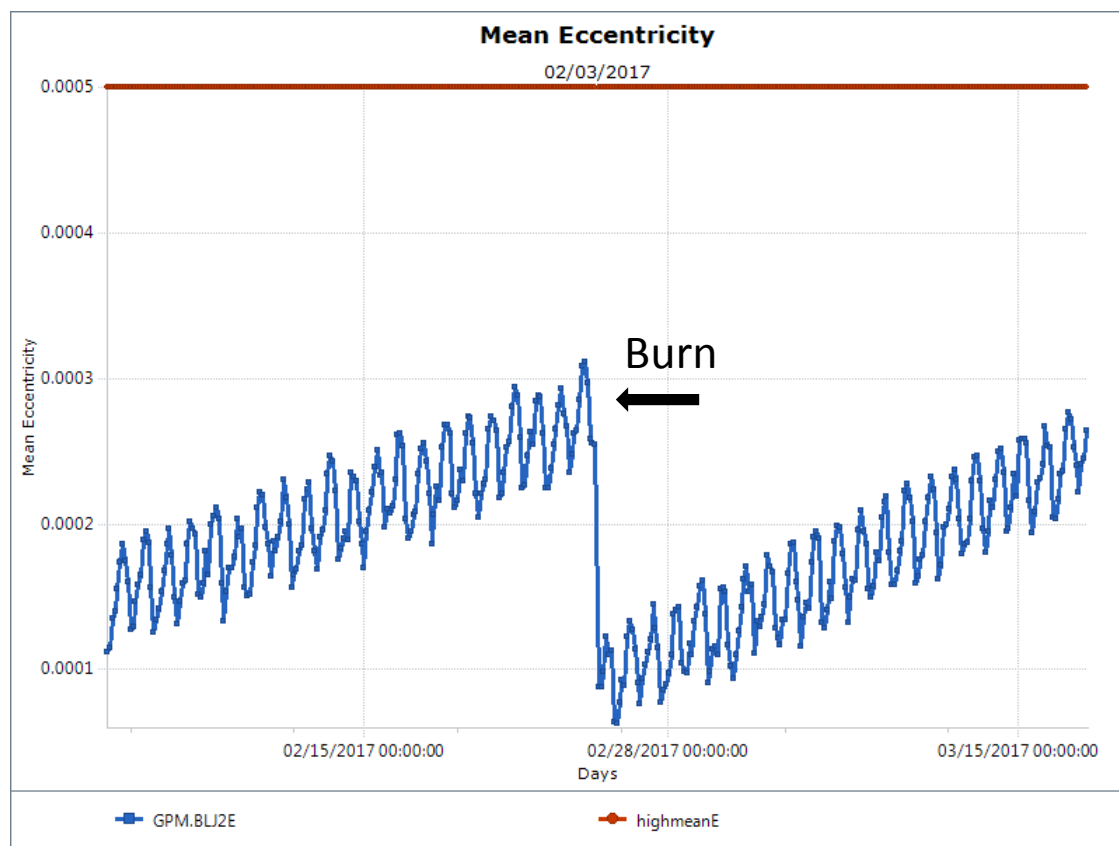
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- Prelaunch analysis predicted a potential mission lifetime extending to 2035, and until solar minimum, the predictions were mostly being borne out



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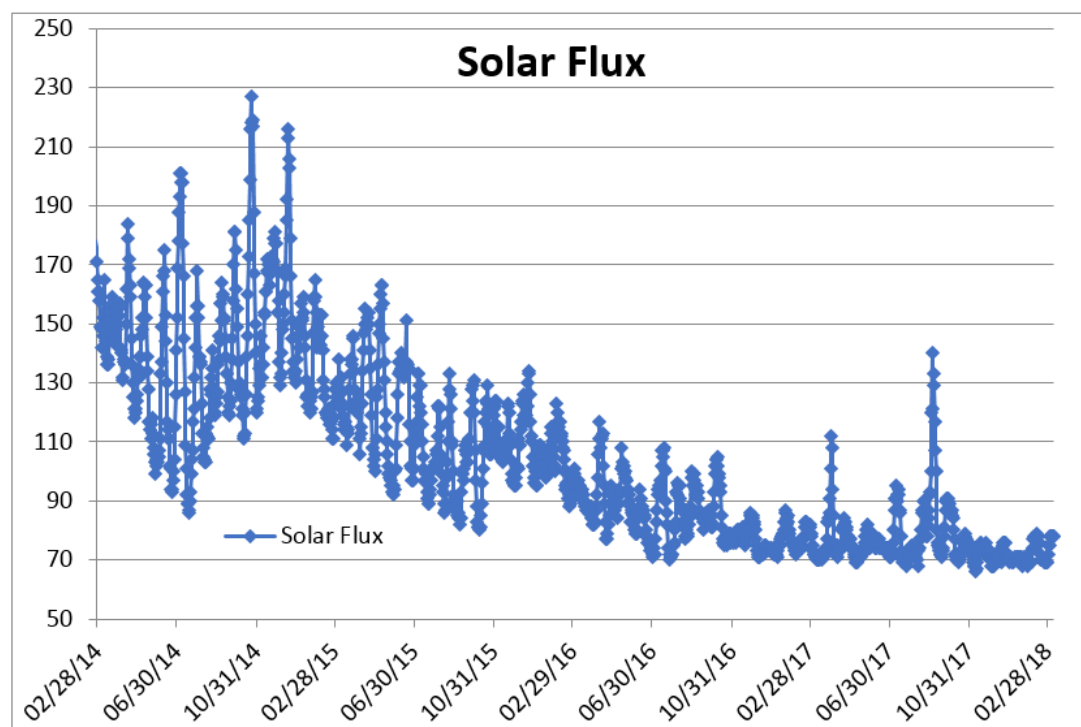


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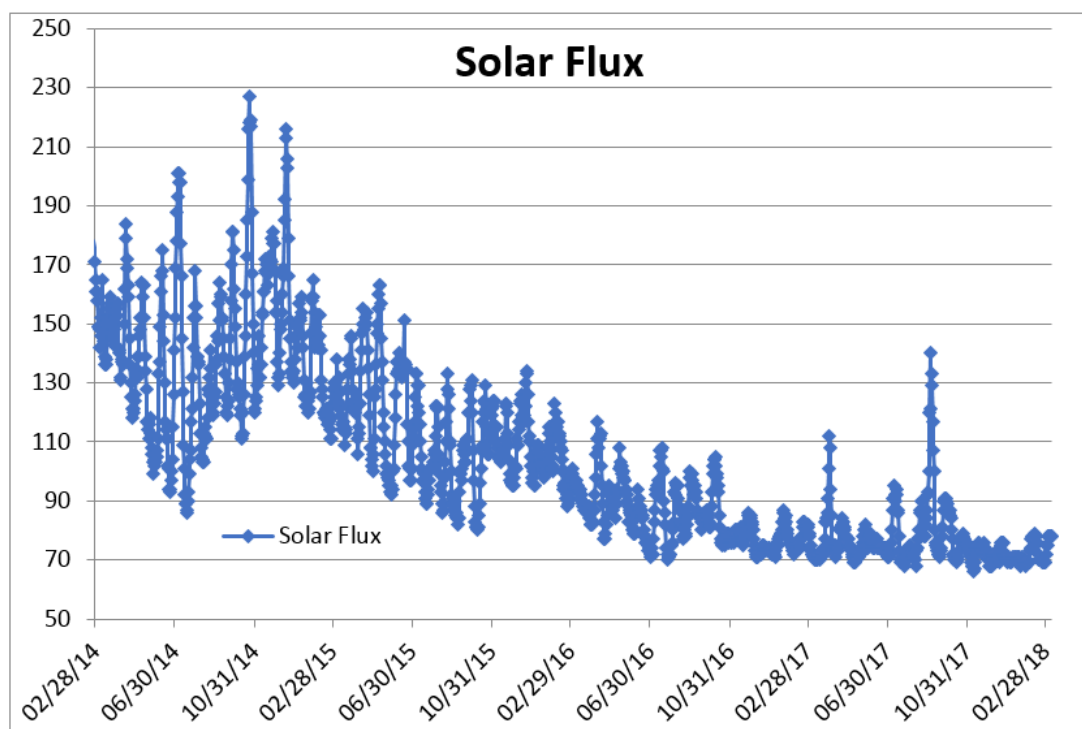
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- **A comprehensive lifetime analysis model must take all of these inputs into account to project fuel usage**

Solar minimum – F10.7 cm Radio Flux



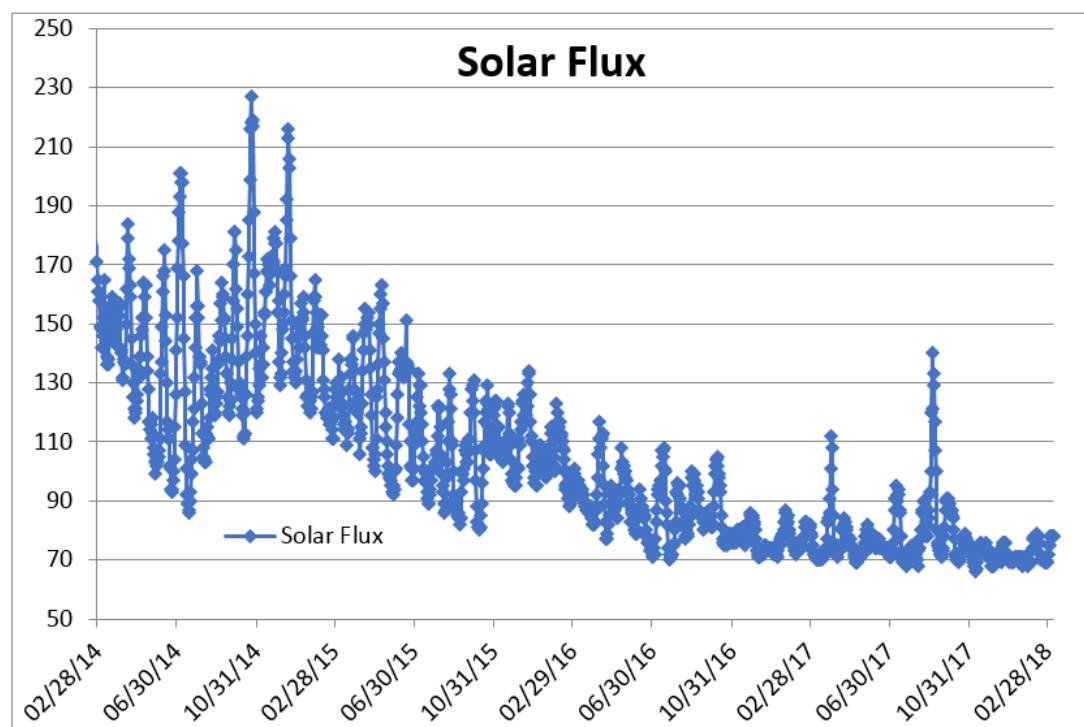
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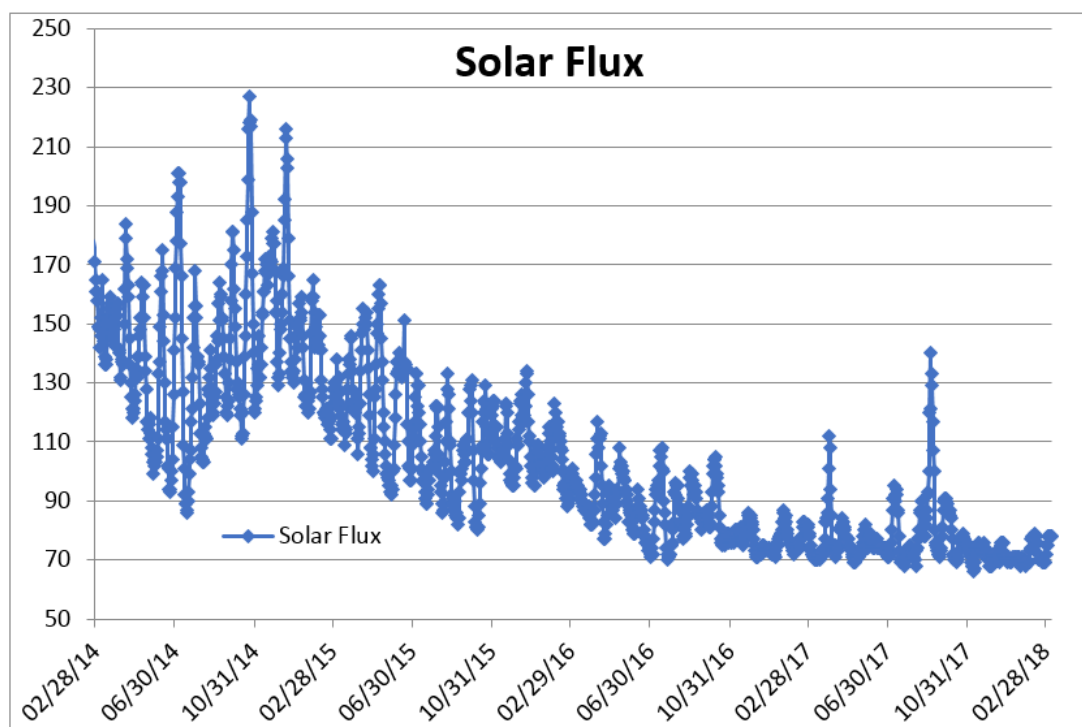
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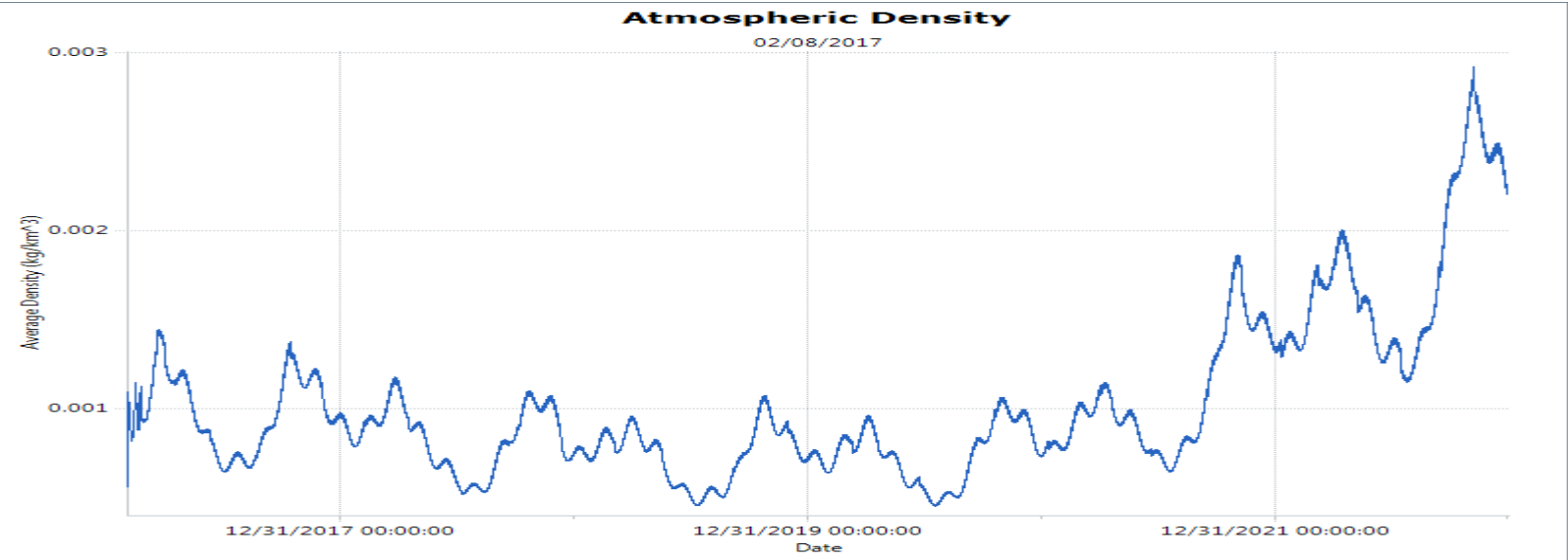
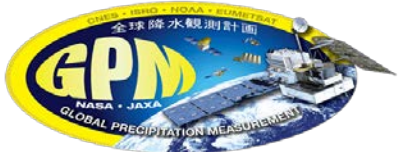


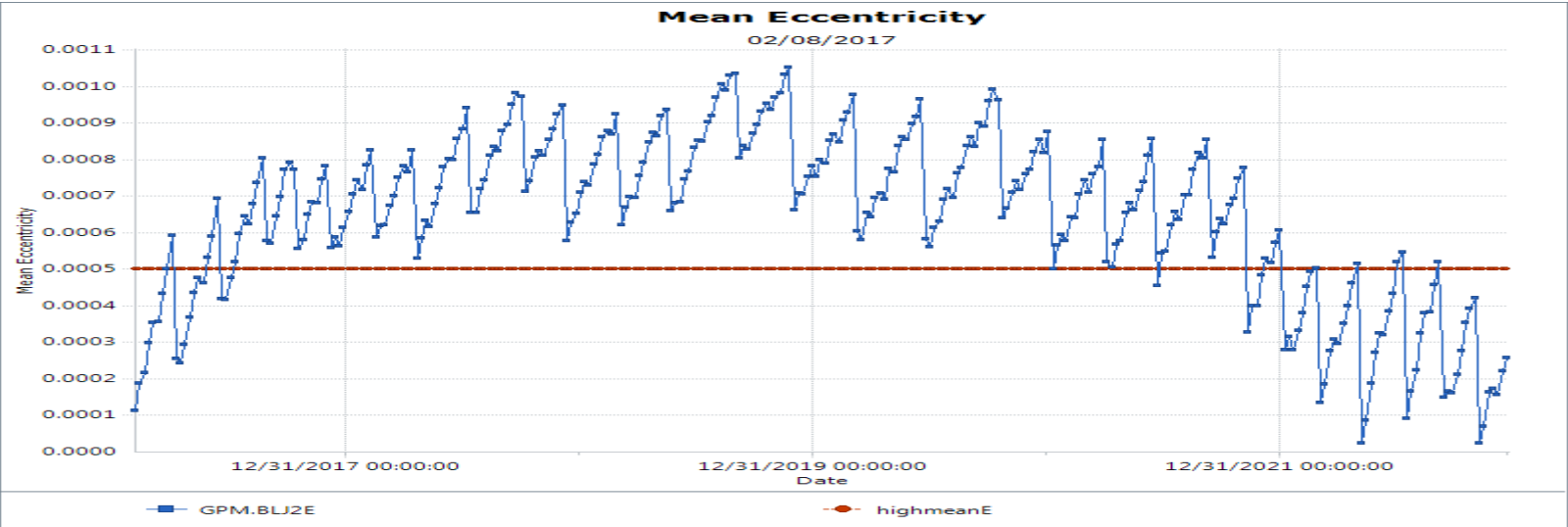
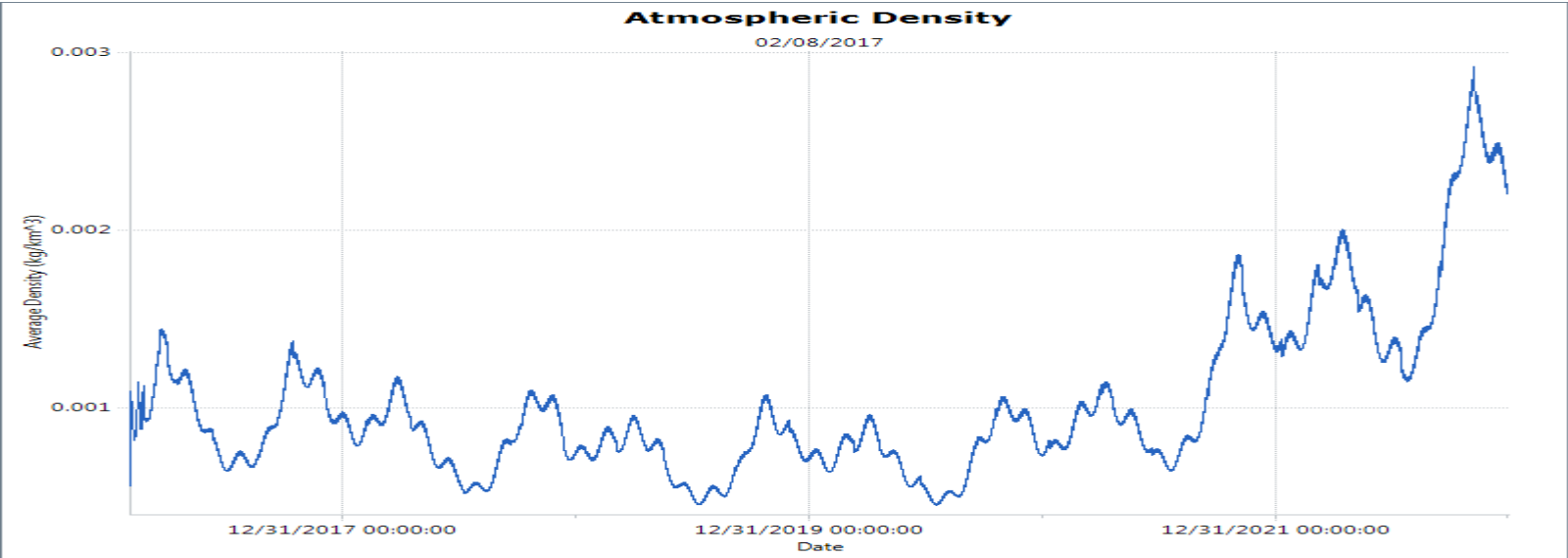
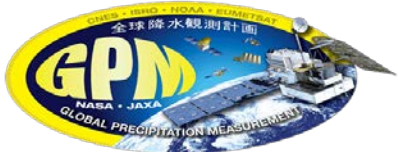
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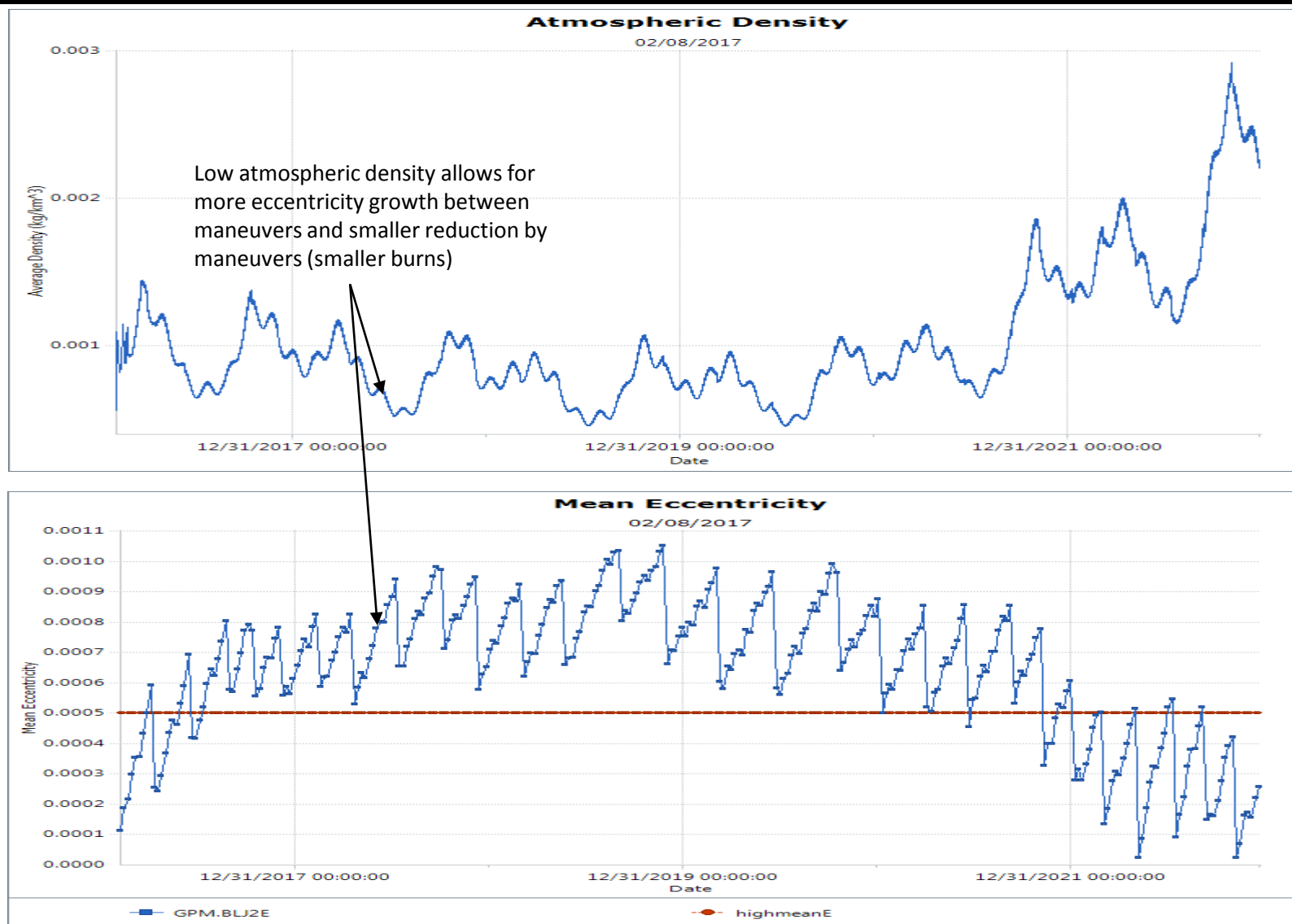
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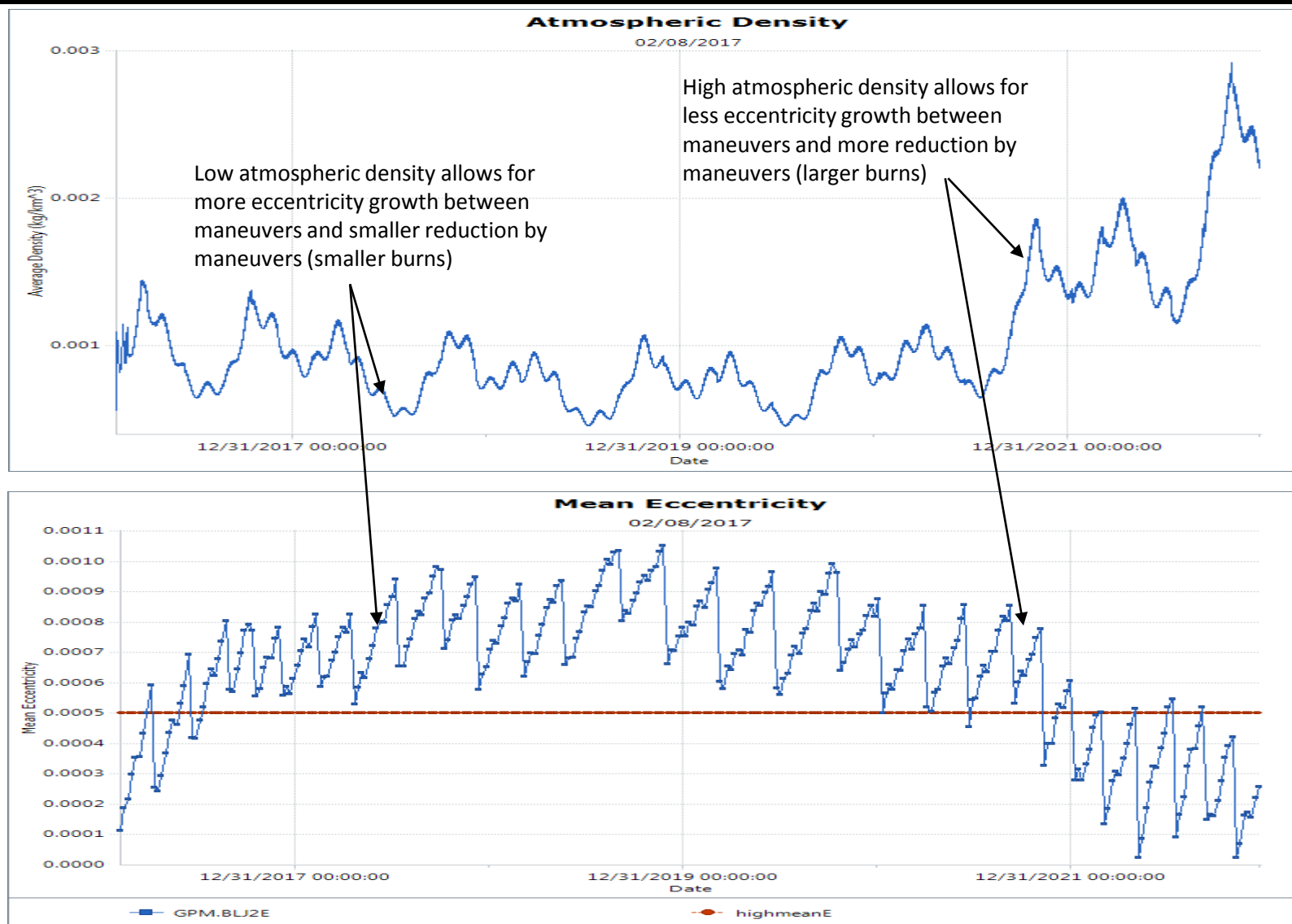


- Schatten predictions showed the solar minimum starting in mid-2016 and then extending through 2020
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- However, FDS engineers began to predict something unexpected: DMUs would be too infrequent and of insufficient size to control ECC within limits

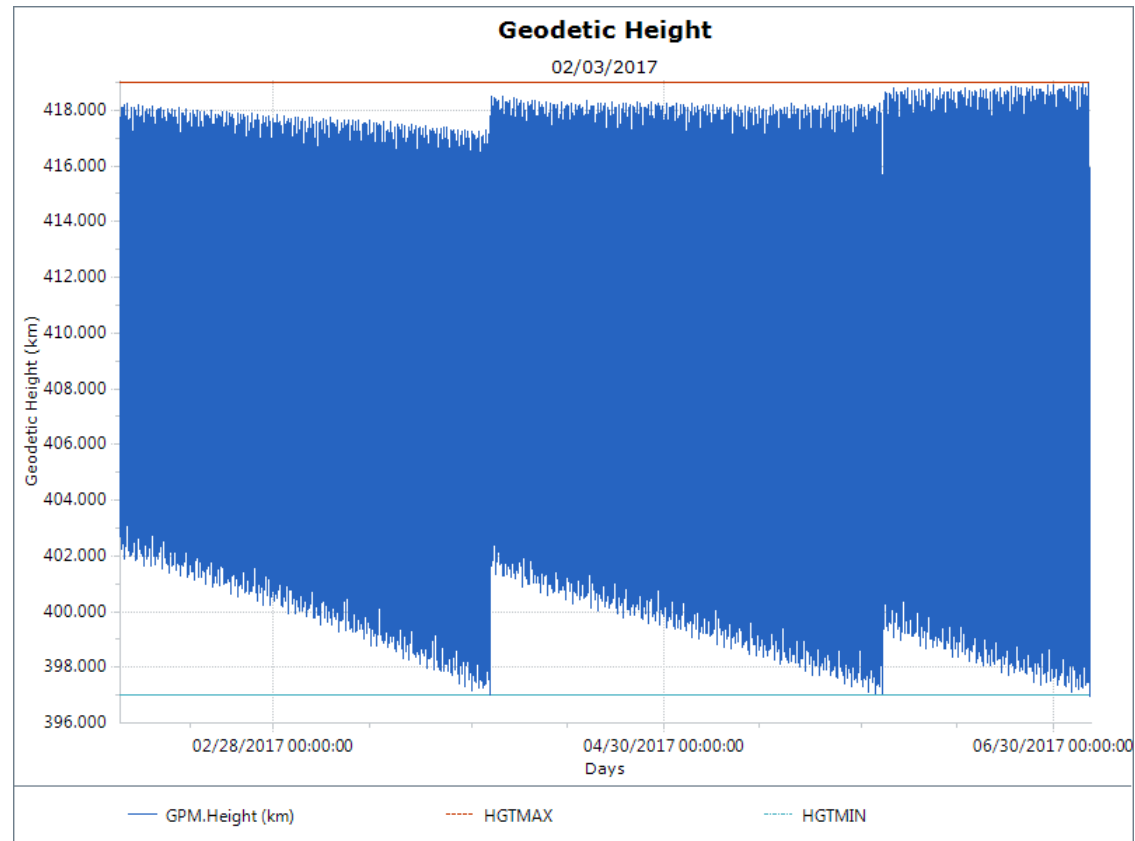






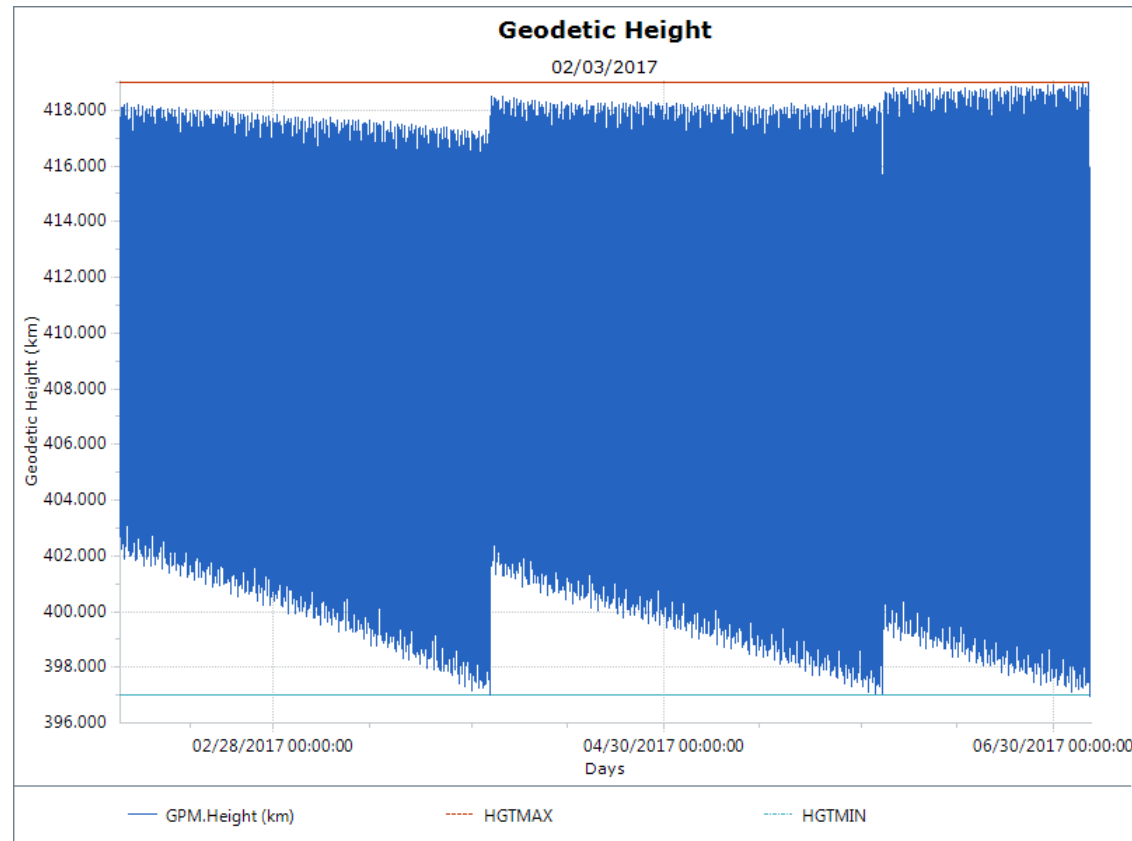


Growth in ECC
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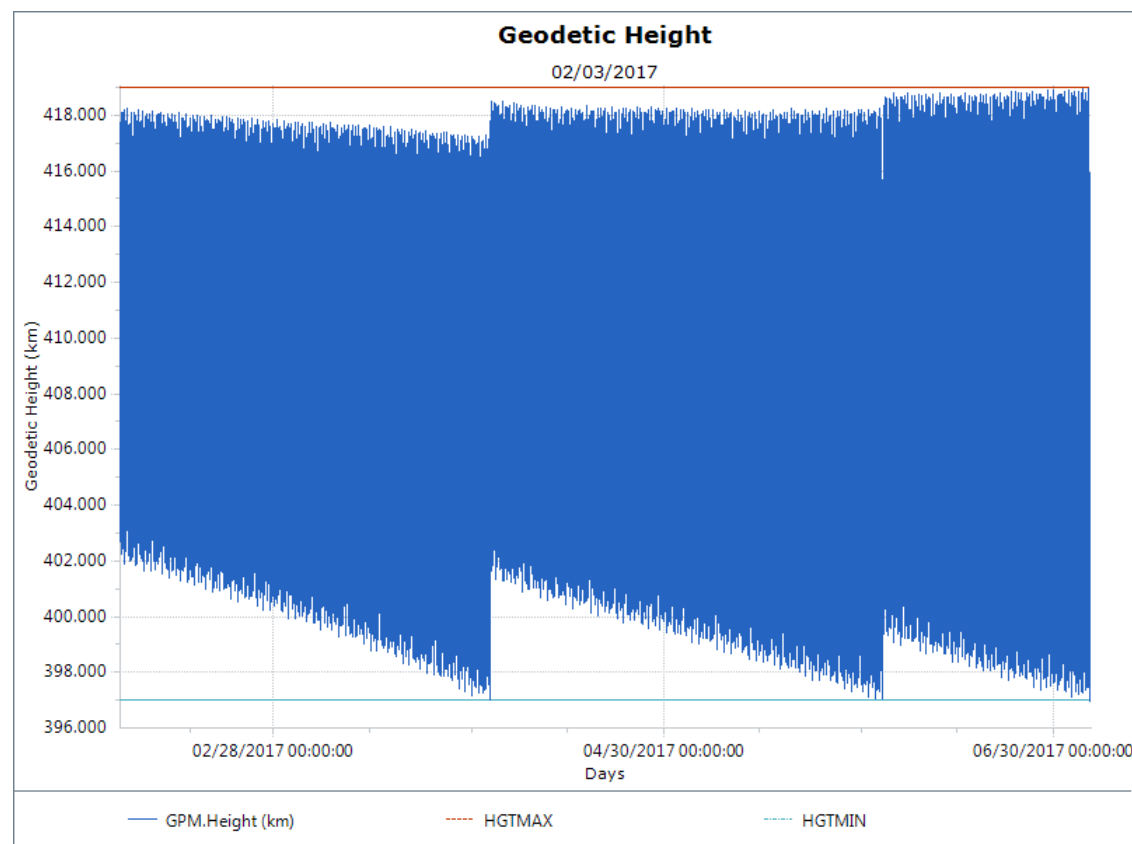
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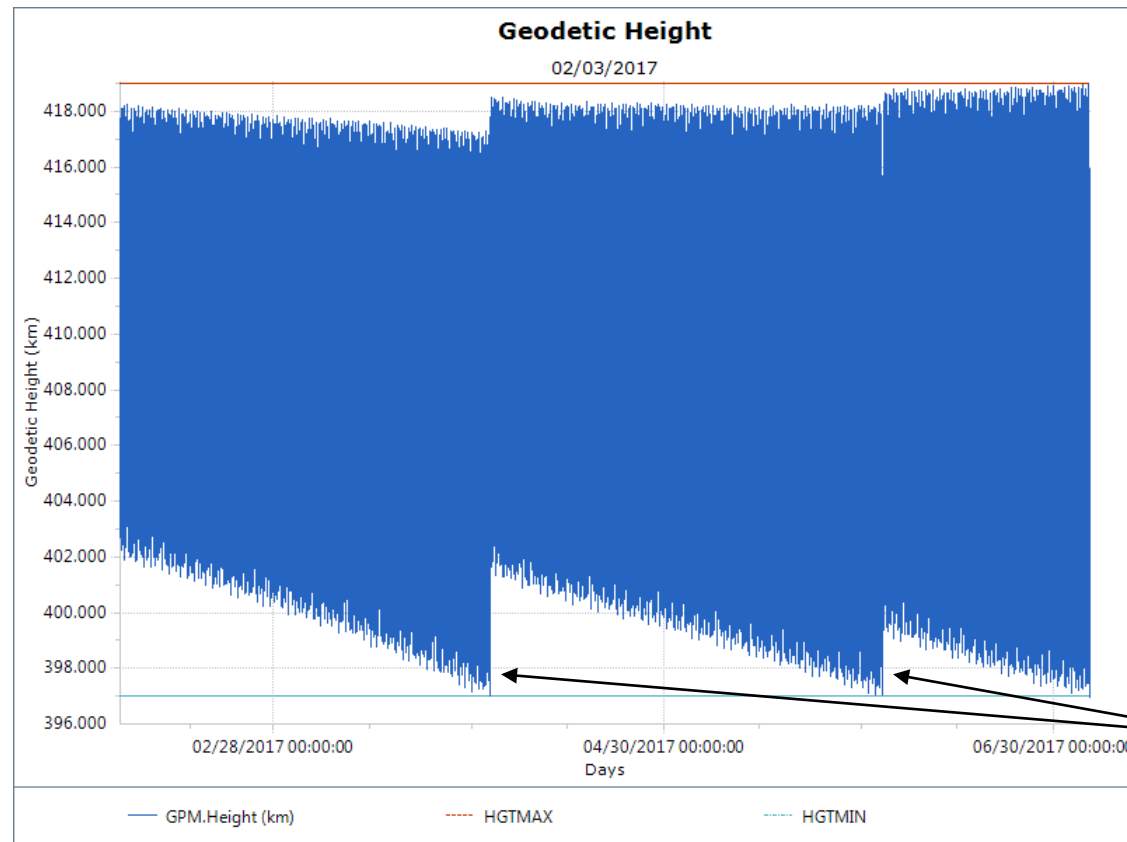
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Any DMU large enough to control the ECC growth will cause a violation of the HGT limits

This example shows two normal DMUs targeted before the scheme fails



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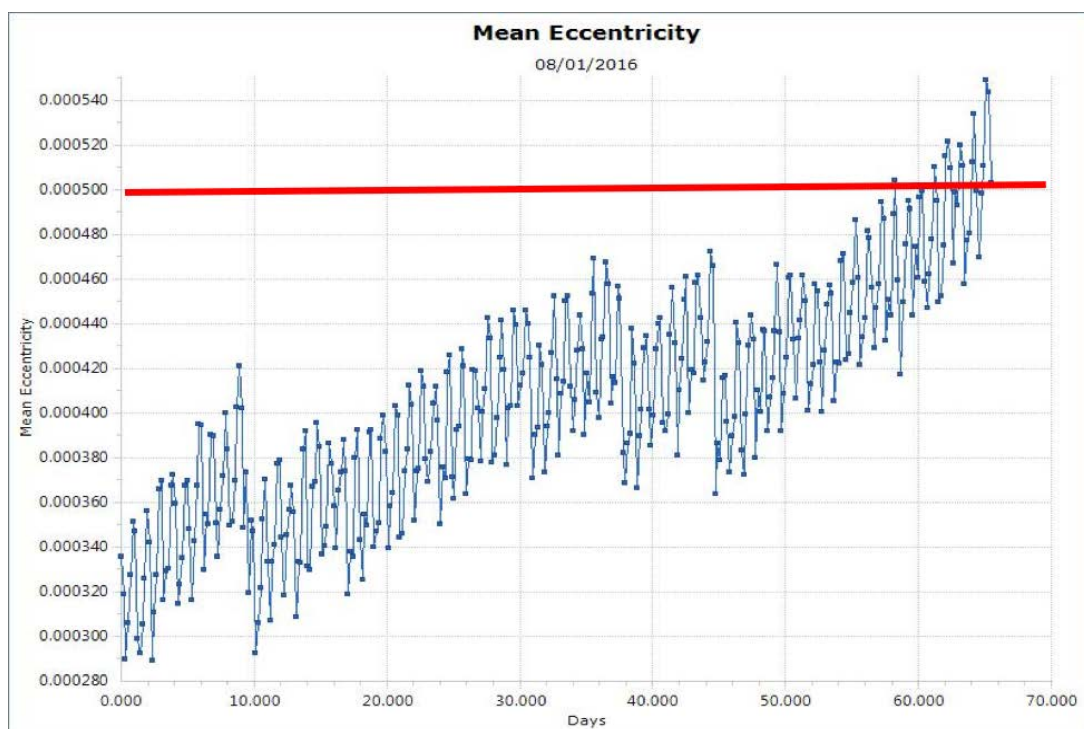
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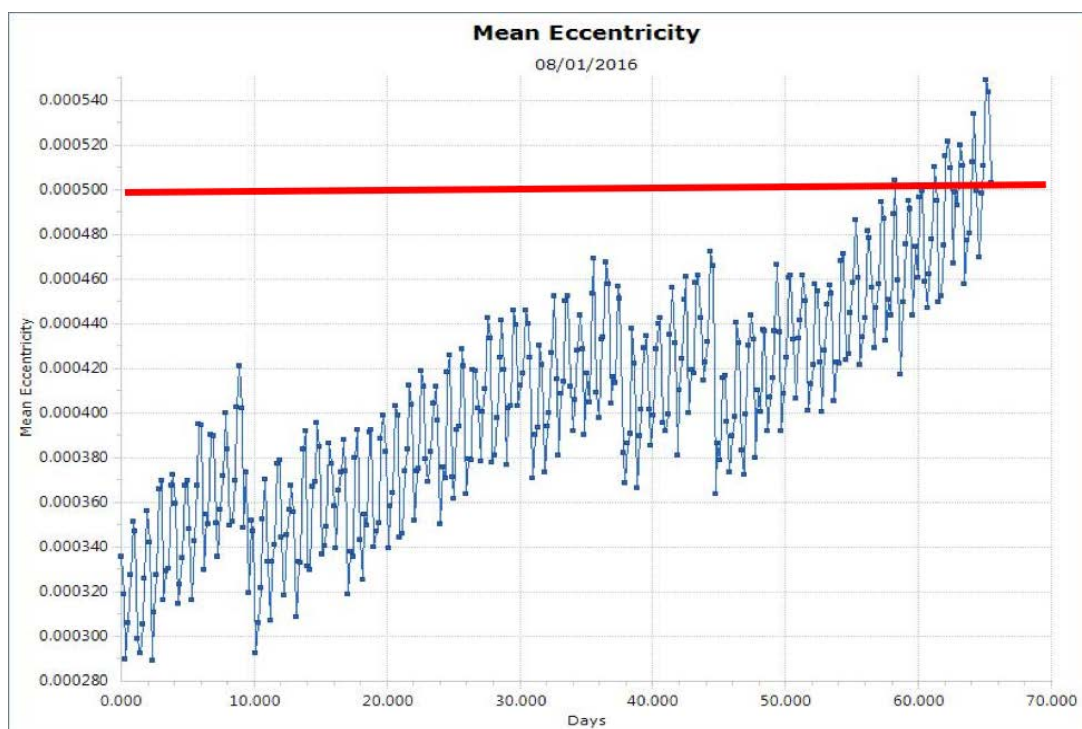
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- **The third was to artificially increase spacecraft drag by flying a different solar array profile**

ECC – One-Week Maneuver Cadence

- Idea was that smaller and more frequent maneuvers might decrease the ECC faster

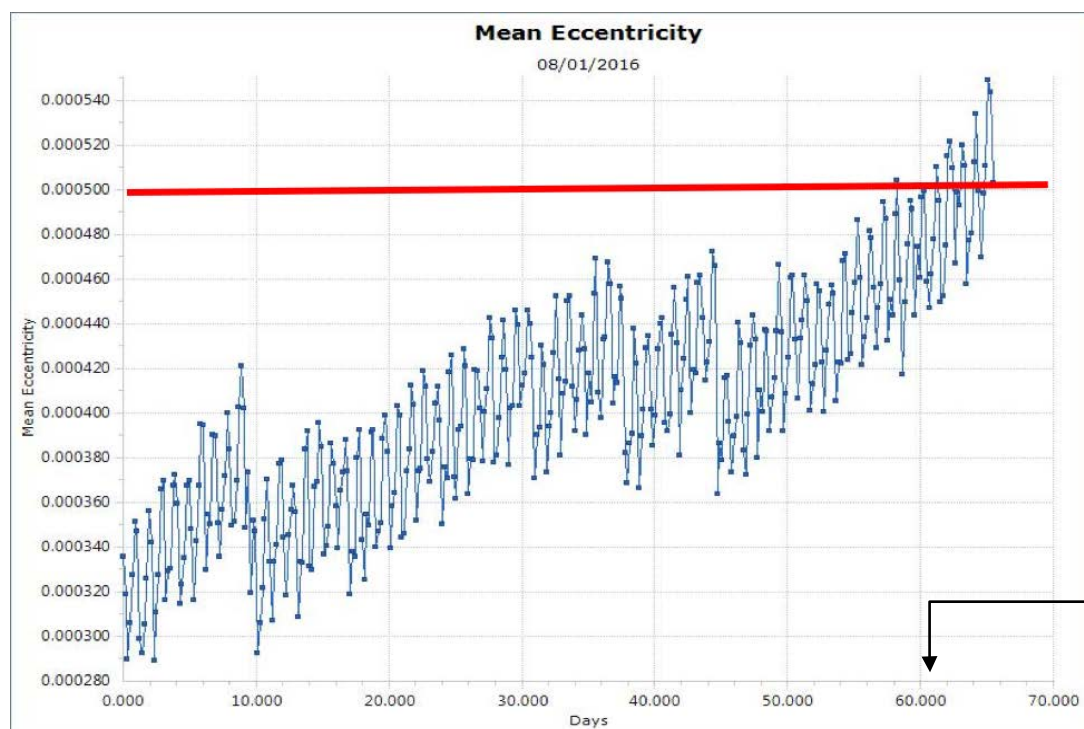


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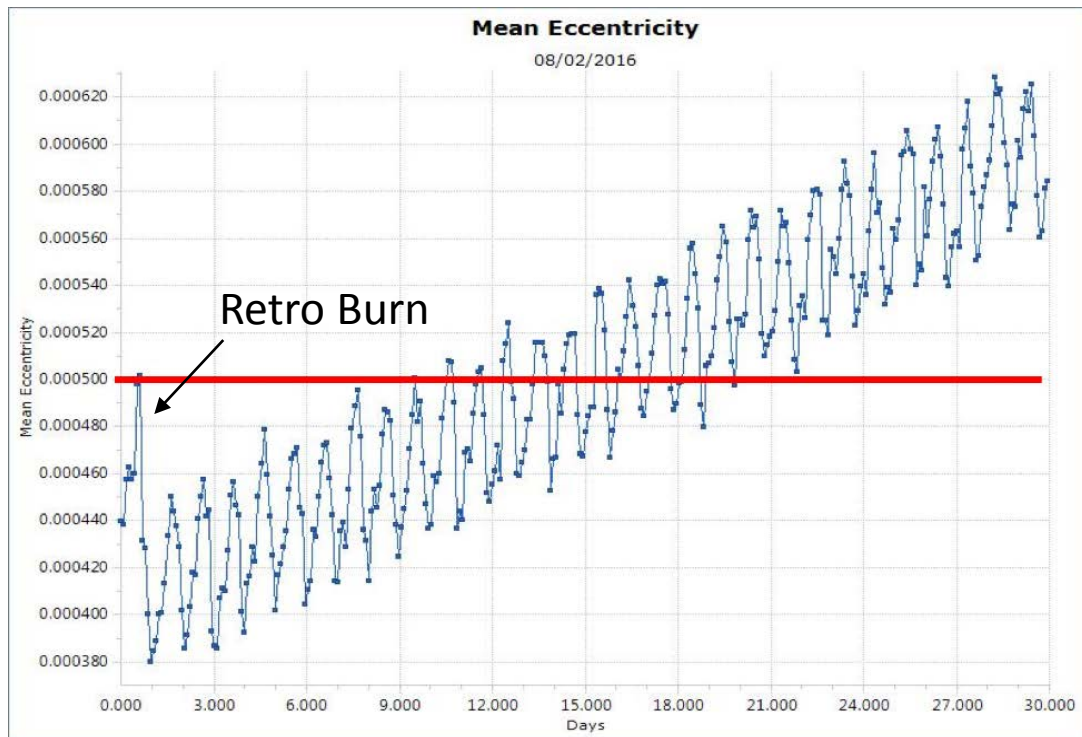
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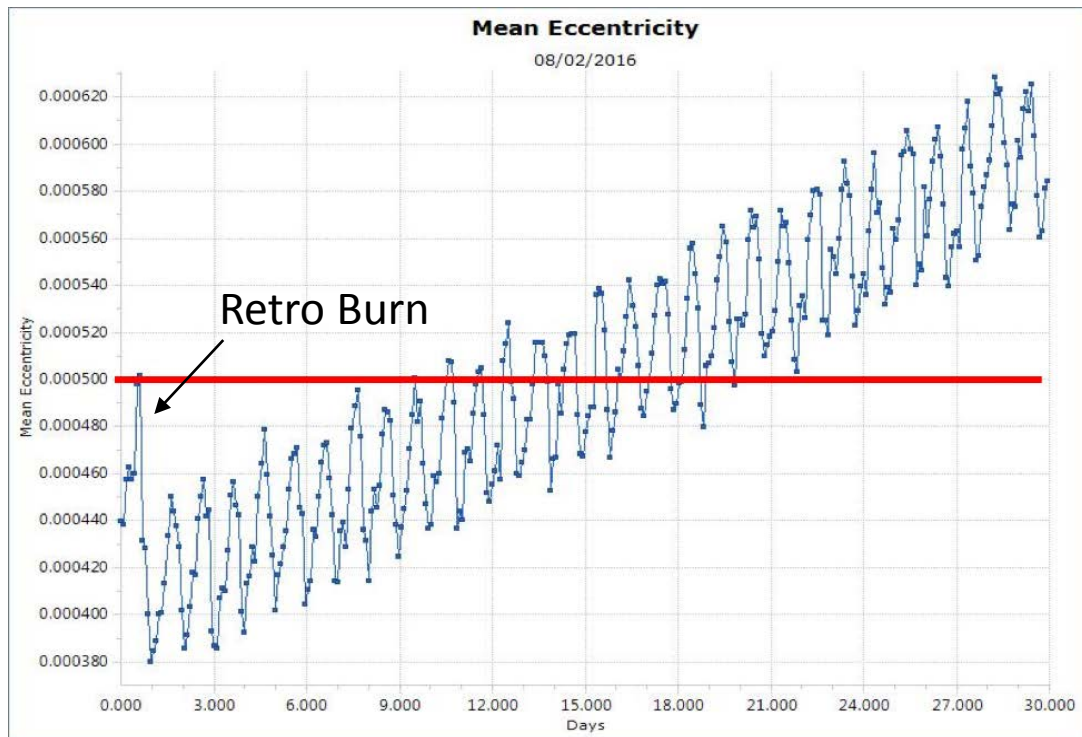
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- Result was a violation of the ECC and HGT requirements within two months (i.e. quicker failure than normal targeting).

ECC – Retrograde Maneuver



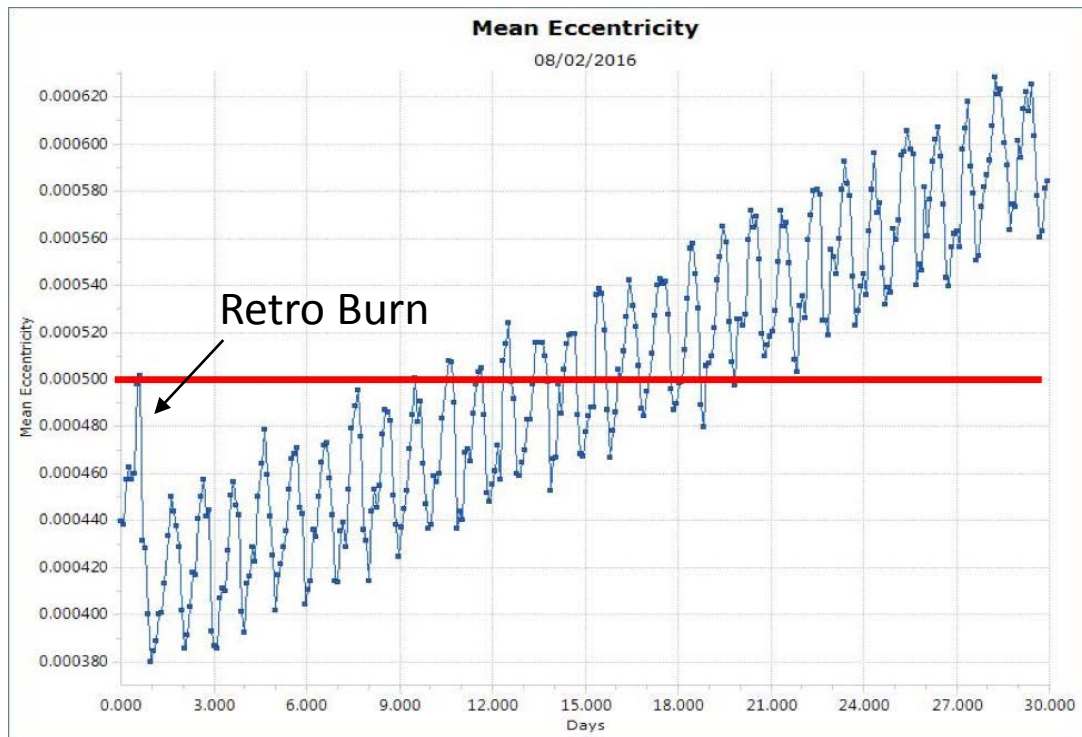
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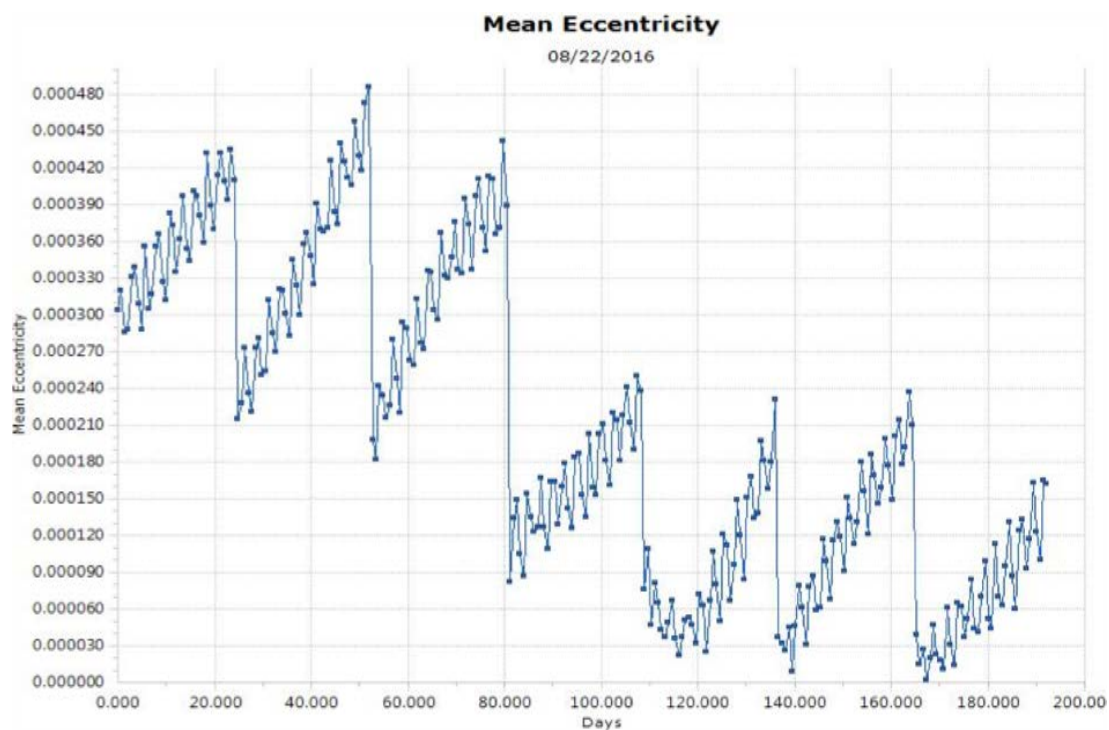
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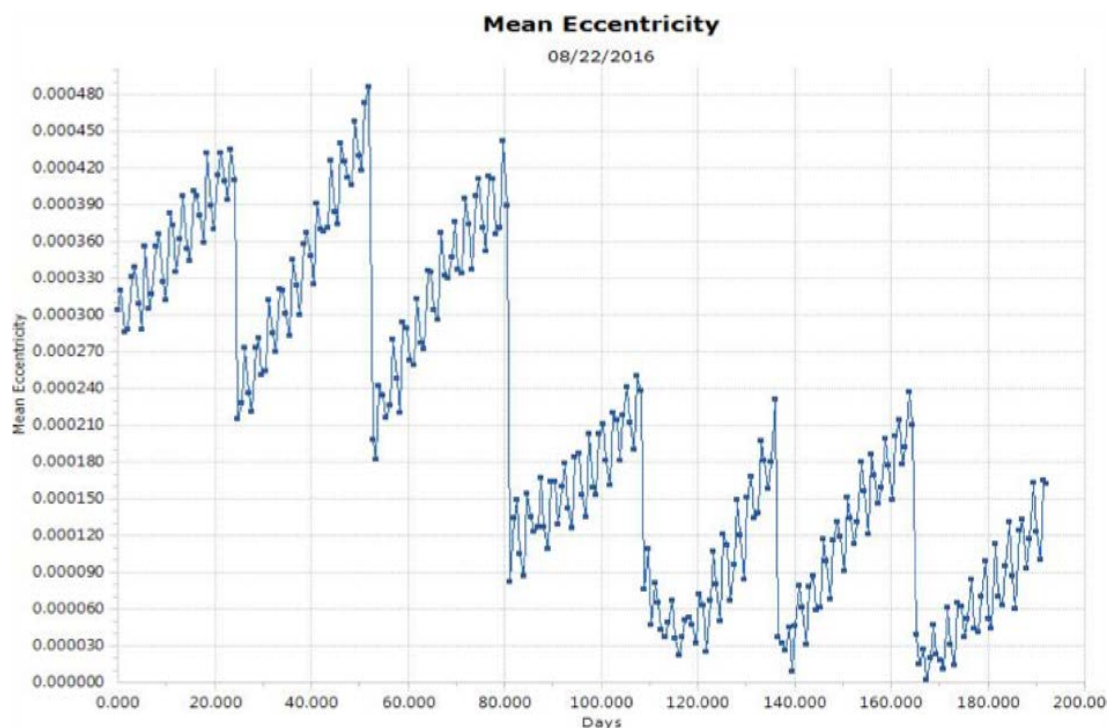
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- An operational test of a 15-sec retro burn had been executed in March 2016; thus, procedures and performance data existed
- However, the team was concerned that using retro burns to maintain the orbit across the solar minimum would greatly reduce the mission lifetime

ECC – High-Drag Array Profile



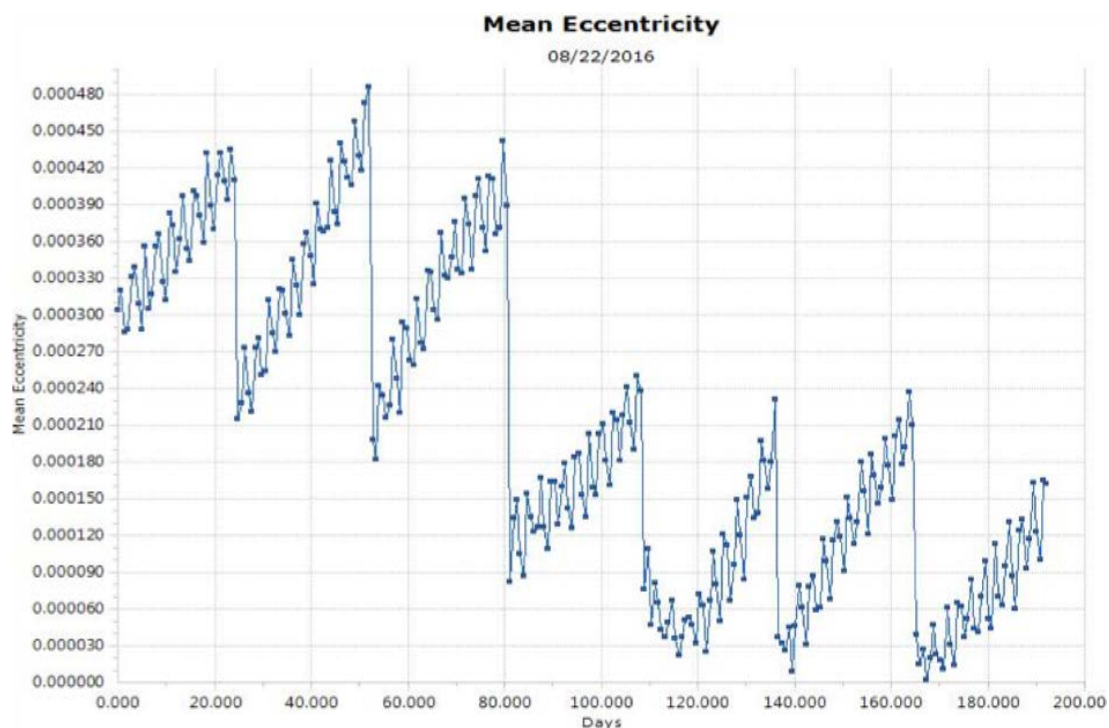
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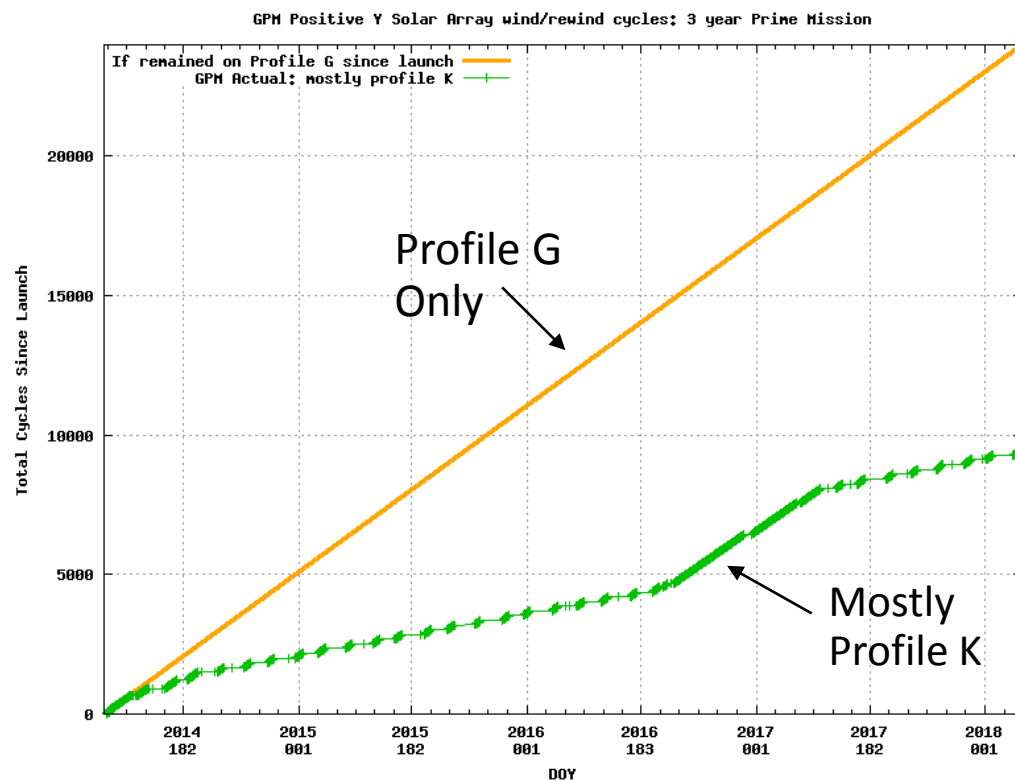
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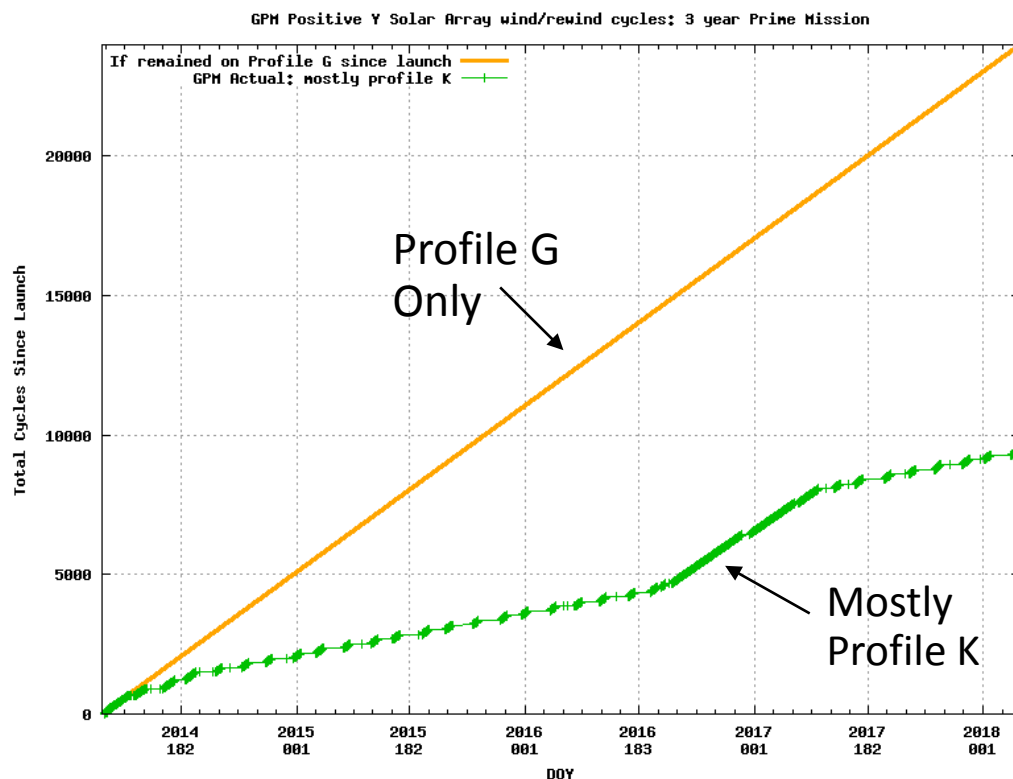
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- **In August 2016, the decision was made to implement this option.**

Gimbal Cycles for Profiles G and K



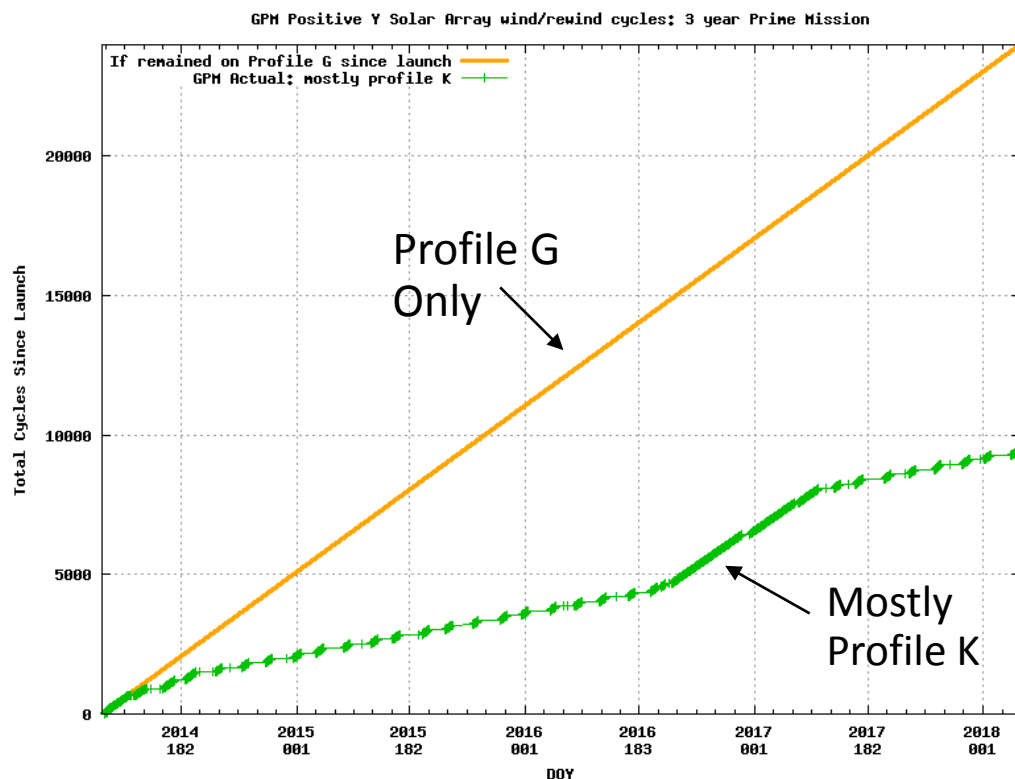
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- Further, this profile was discovered to cause hardware concerns at certain solar beta angles, at which point “Profile K” had to be swapped back in
- Finally, longer-term predictions of orbit evolution showed that ultimately no SA profile would maintain requirements through the end of solar minimum



- **FDS engineers conduct a formal analysis of the GPM lifetime on a biannual basis (Spring and Fall)**

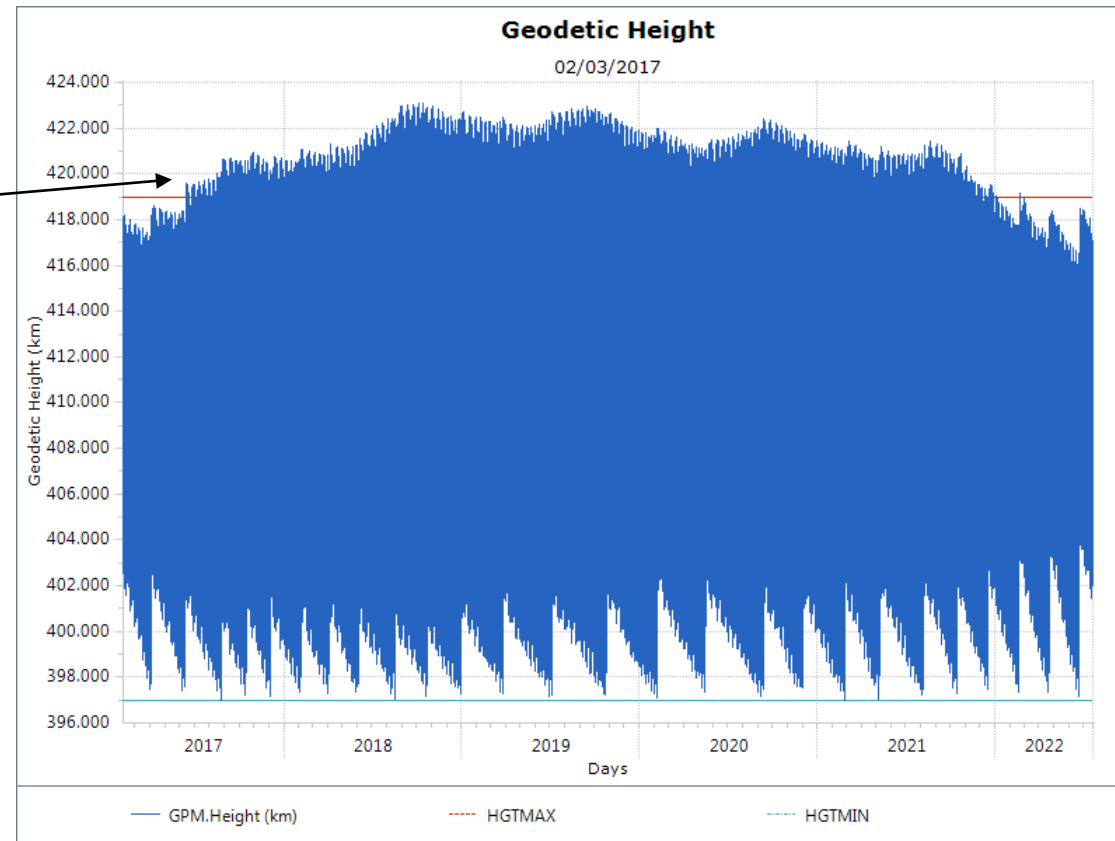


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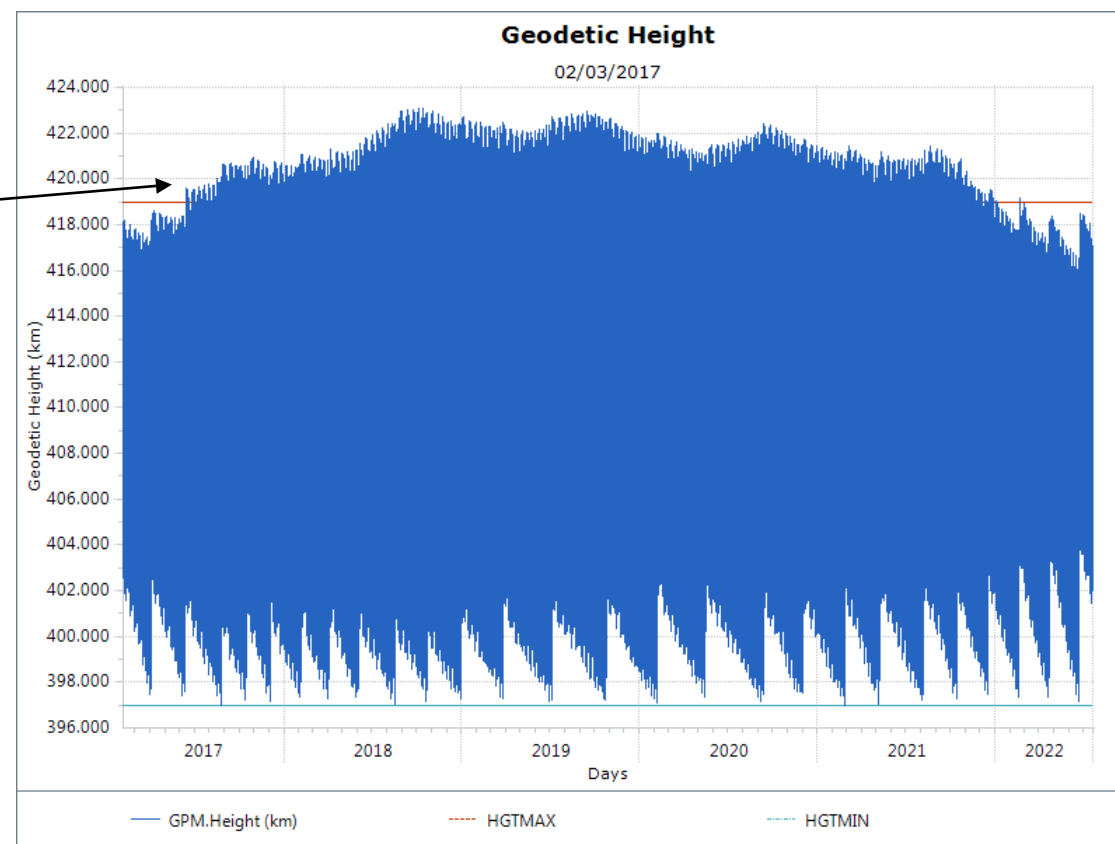
- **FDS engineers conduct a formal analysis of the GPM lifetime on a biannual basis (Spring and Fall)**
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- **The script can thus serve as a testbed for evaluating, and perhaps eliminating, new candidates**

SMA-only targeting works over mission lifetime, but fails to satisfy HGT limits during low drag...



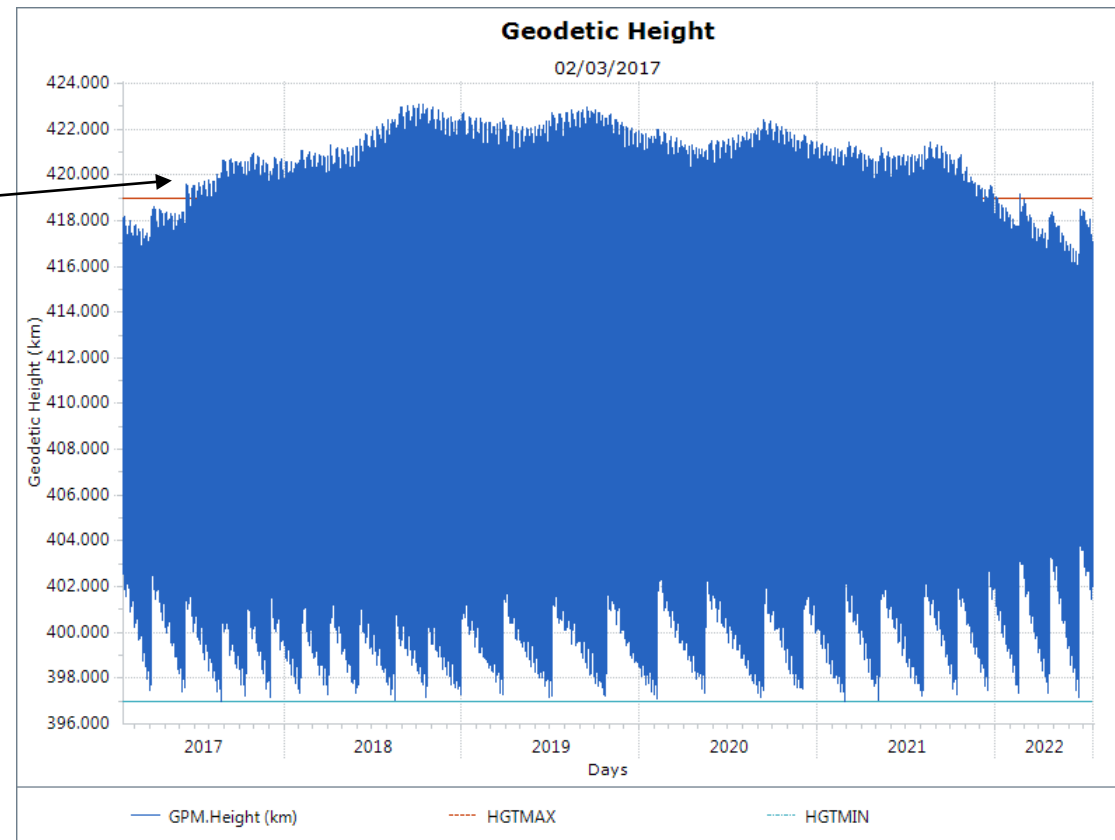
SMA-only targeting works over mission lifetime, but fails to satisfy HGT limits during low drag...

...while schemes accounting for HGT start to fail early in solar minimum



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...while schemes accounting for HGT start to fail early in solar minimum



Any approach based on reduced maneuver cadence results in a quicker targeting failure, even if the lower operational limit on duration is waived



- **For GPM's orbit, an approximate rule of thumb is that the ECC limit is reached when the spread between Min and Max HGT is 19 km (out of 22 km box size)**

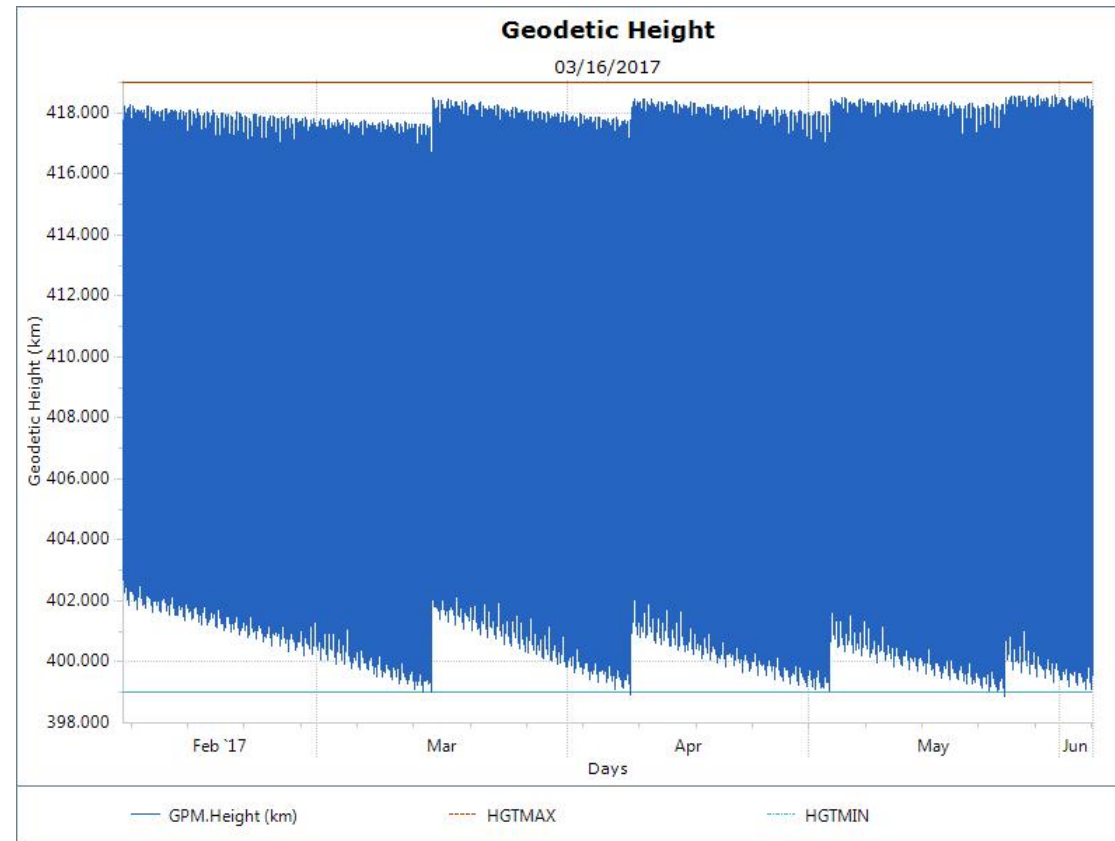


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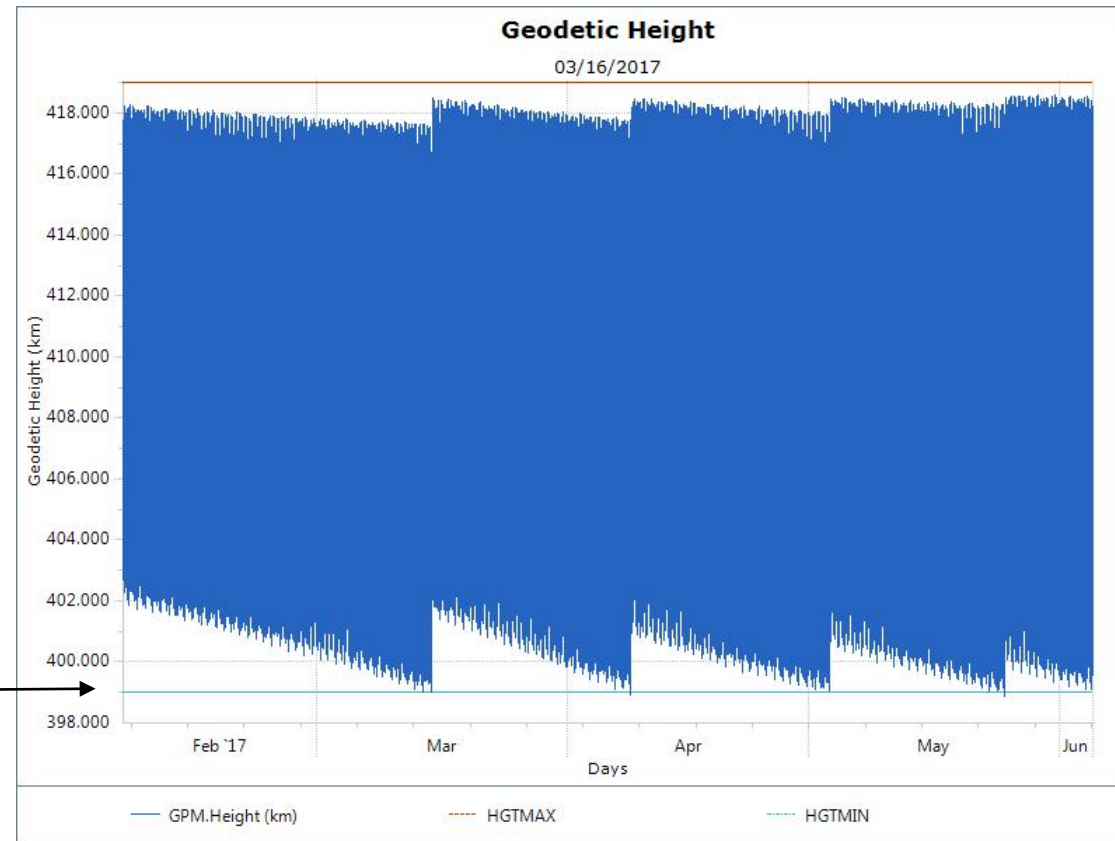
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- **Thus in low drag, it is possible for the ECC limit to be violated before the minimum HGT limit is reached**
- **To ensure both HGT and ECC requirements are met, it is necessary to add ECC as a trigger for maneuvers**

Another explored option was to shrink the HGT swath so as to increase maneuver frequency.



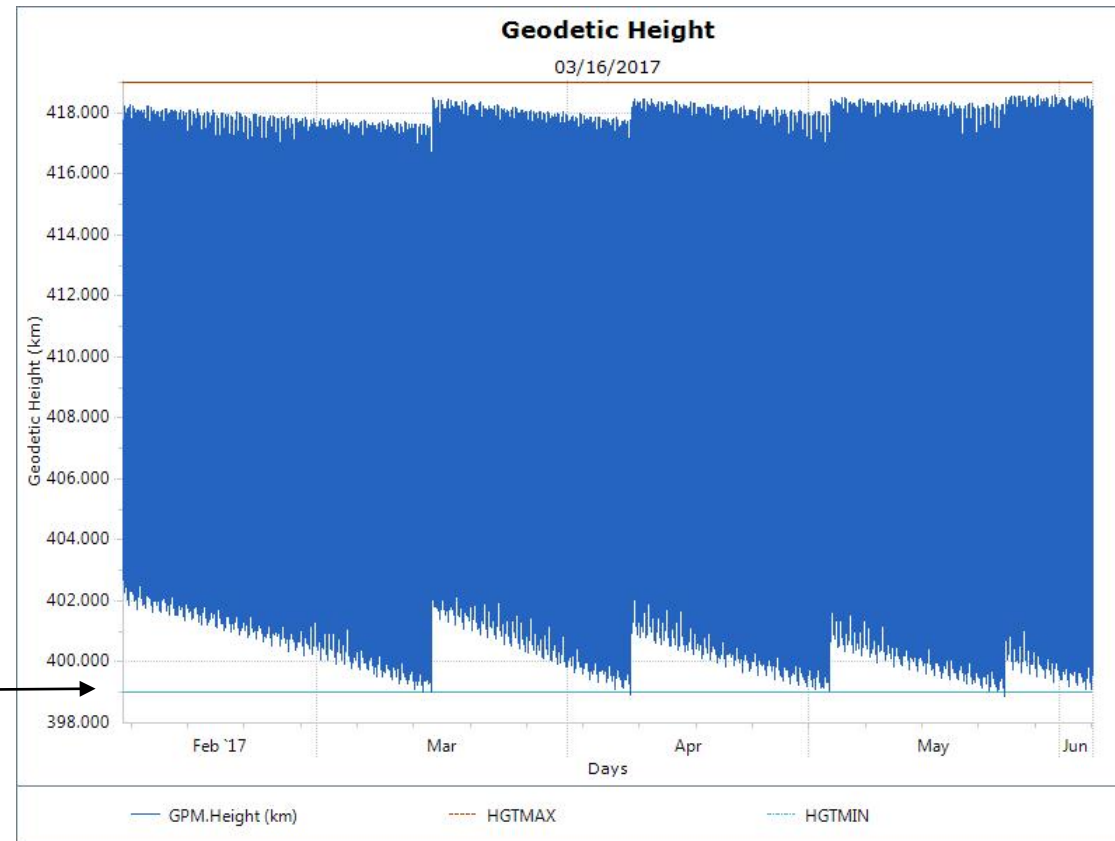
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The lower HGT limit was increased by 2 to 399 km, with maneuvers also triggered by ECC



However, similar to the approaches based on reduced maneuver cadence, the result was only to hasten the targeting failure



- **A relatively exhausting examination of options to address the problem of ECC growth did not identify a solution that relied only on posigrade maneuvers**

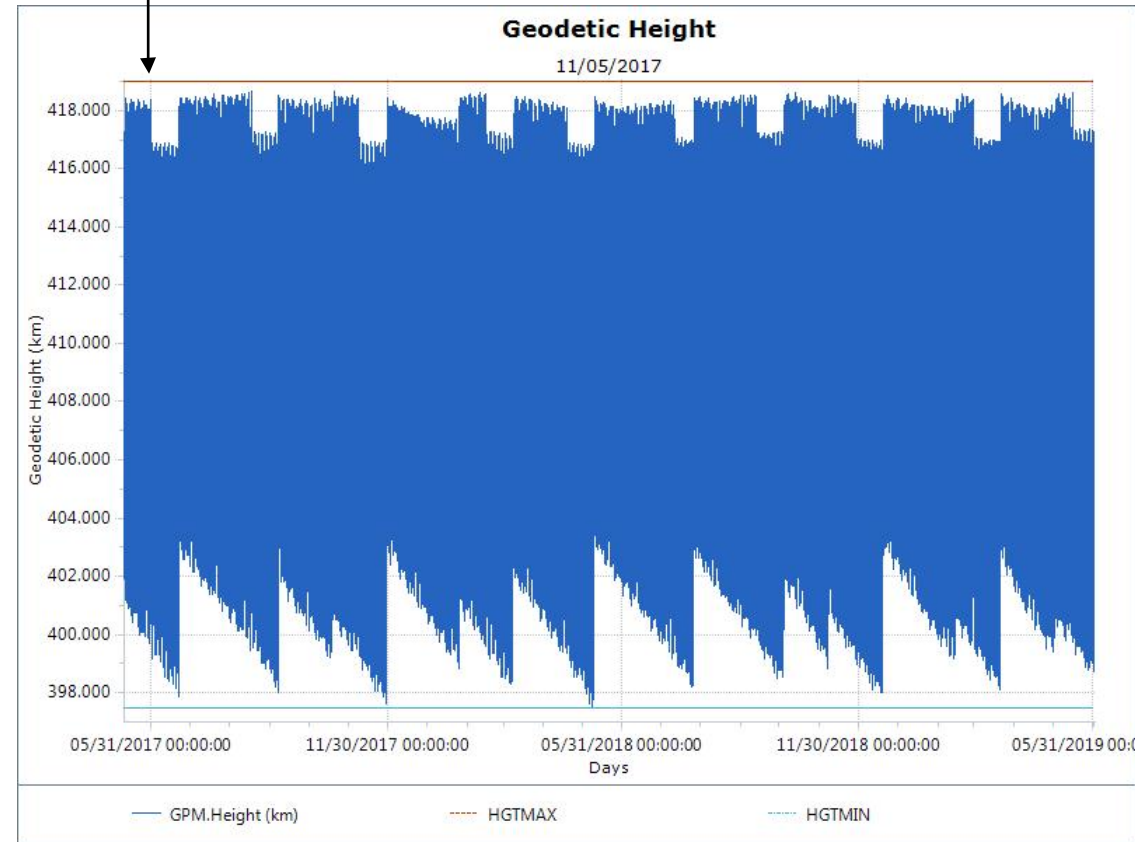


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- **The conclusion was that judicious use of retrograde maneuvers would be the only reliable means of satisfying the orbit requirements in solar minimum**



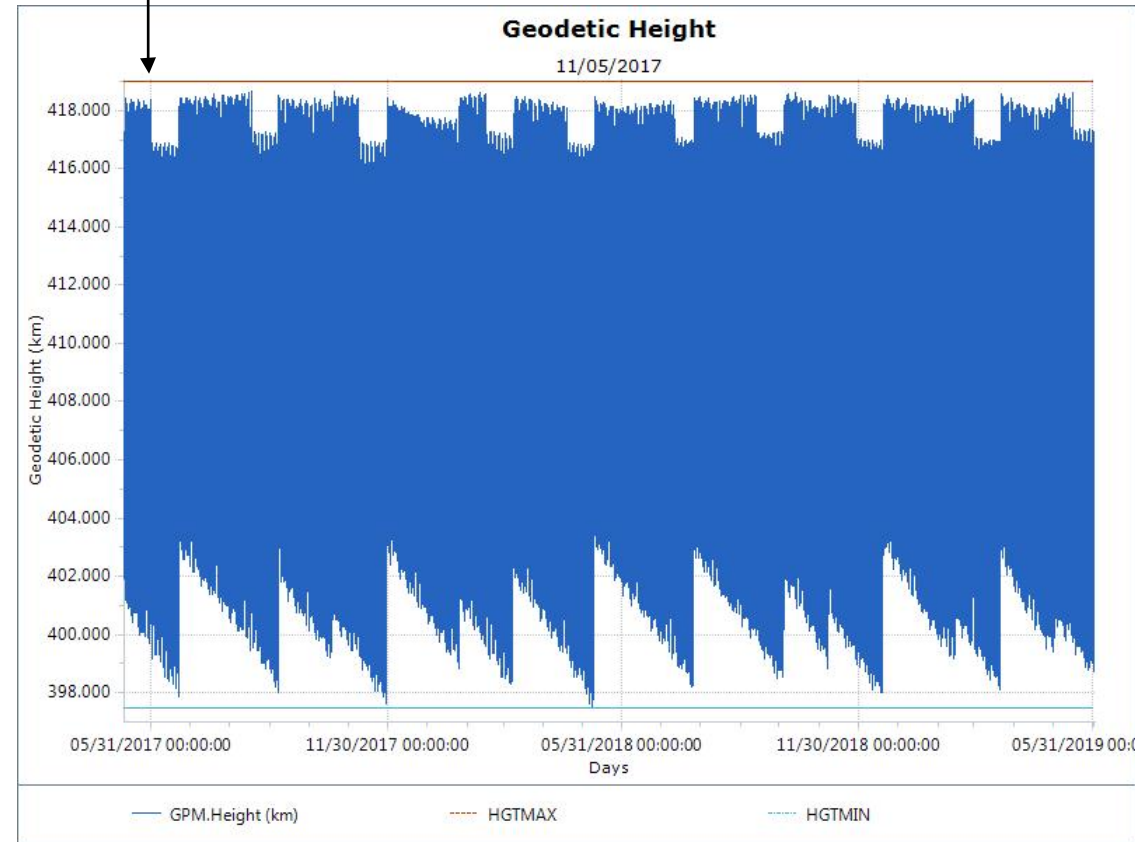
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- **Thus, an actual qualitative measure of the impact to mission lifetime had to be conducted**

The design triggers
a retro upon failure
of the posigrade
targeting scheme.



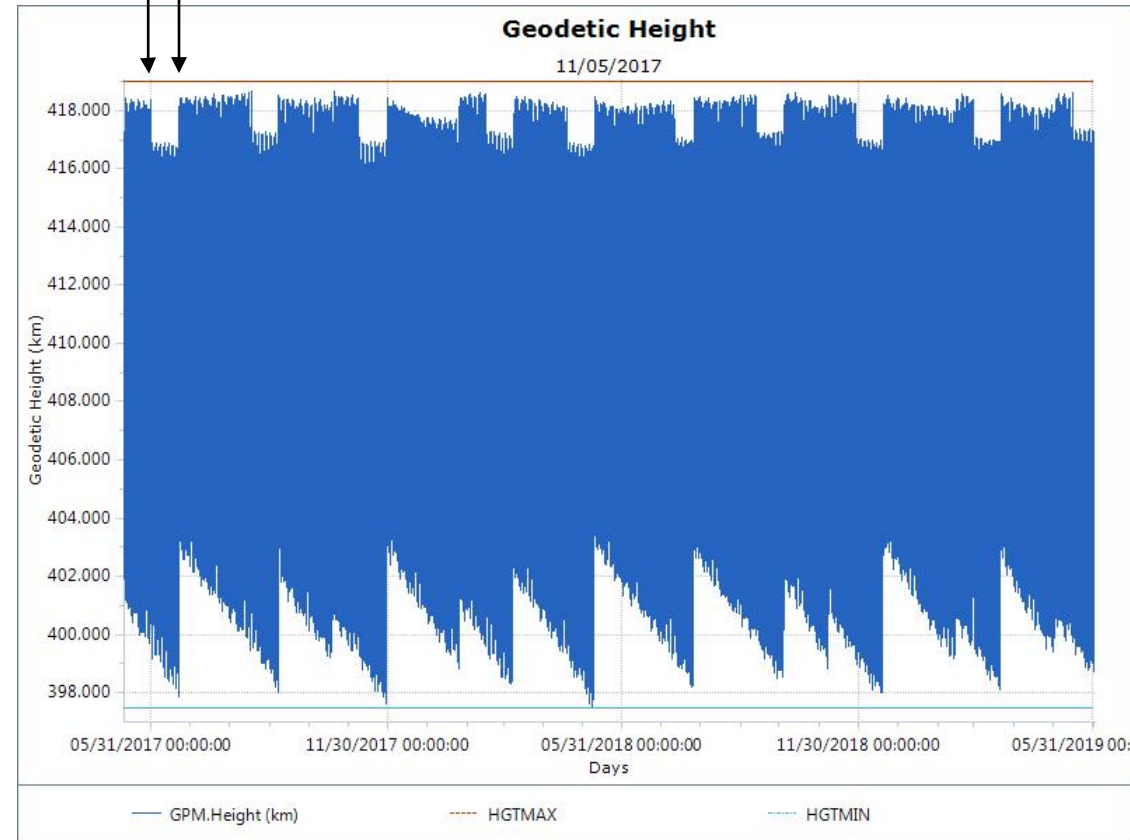
The design triggers a retro upon failure of the posigrade targeting scheme.

Done at perigee, the retro makes a small reduction in ECC and adds room at the top of the HGT control box.



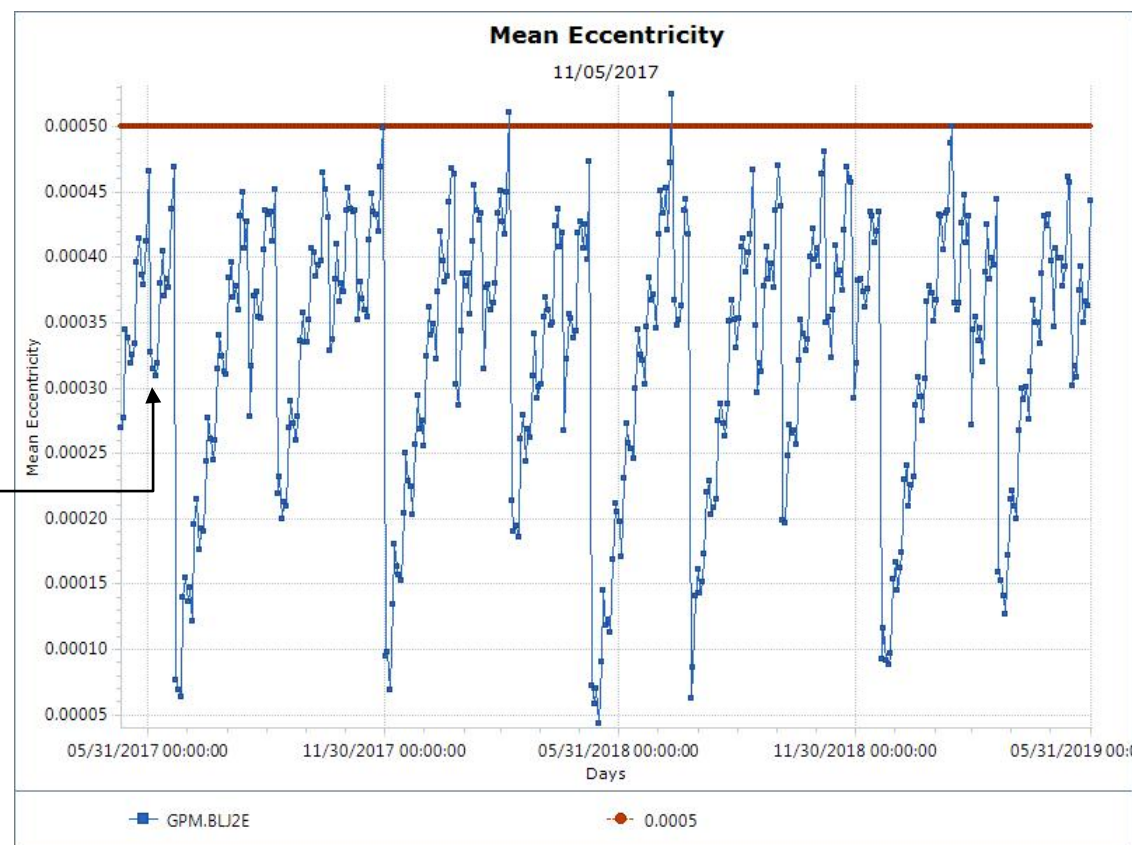
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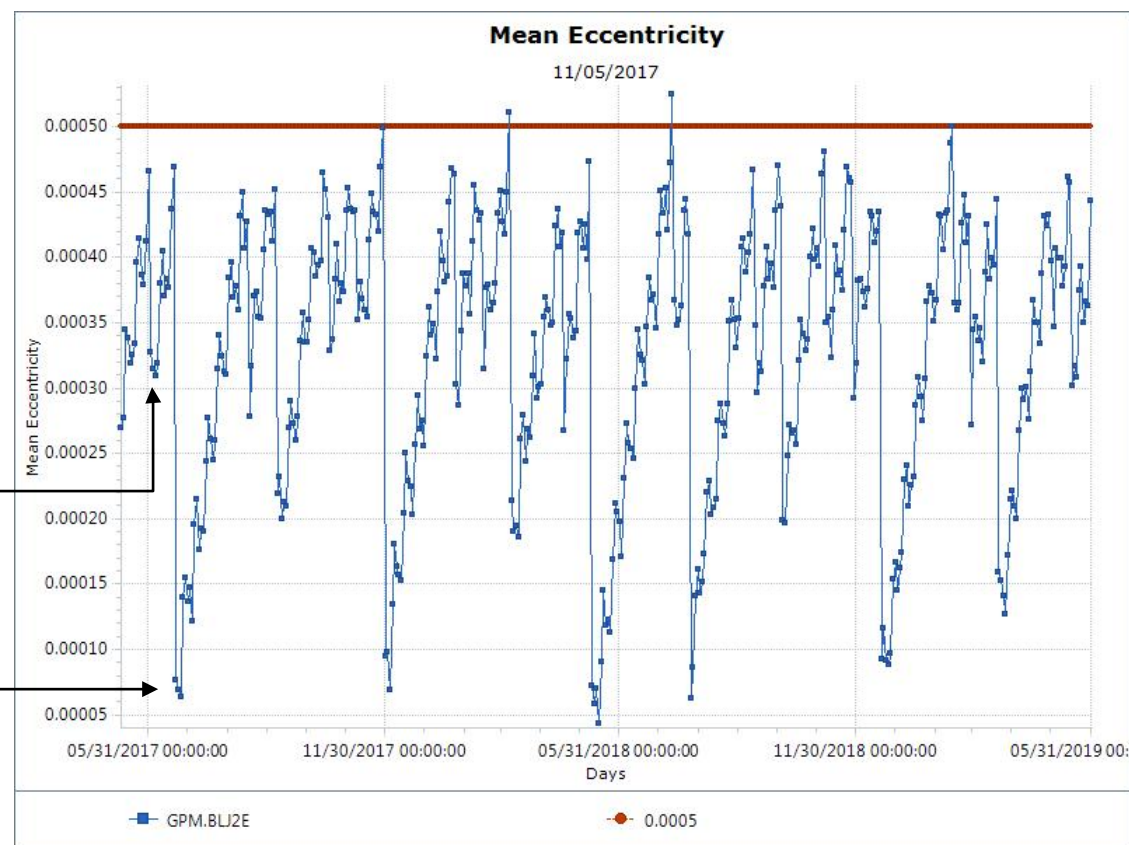


With a lowered Max HGT value, a larger posigrade maneuver can be executed at apogee 2-3 weeks later.

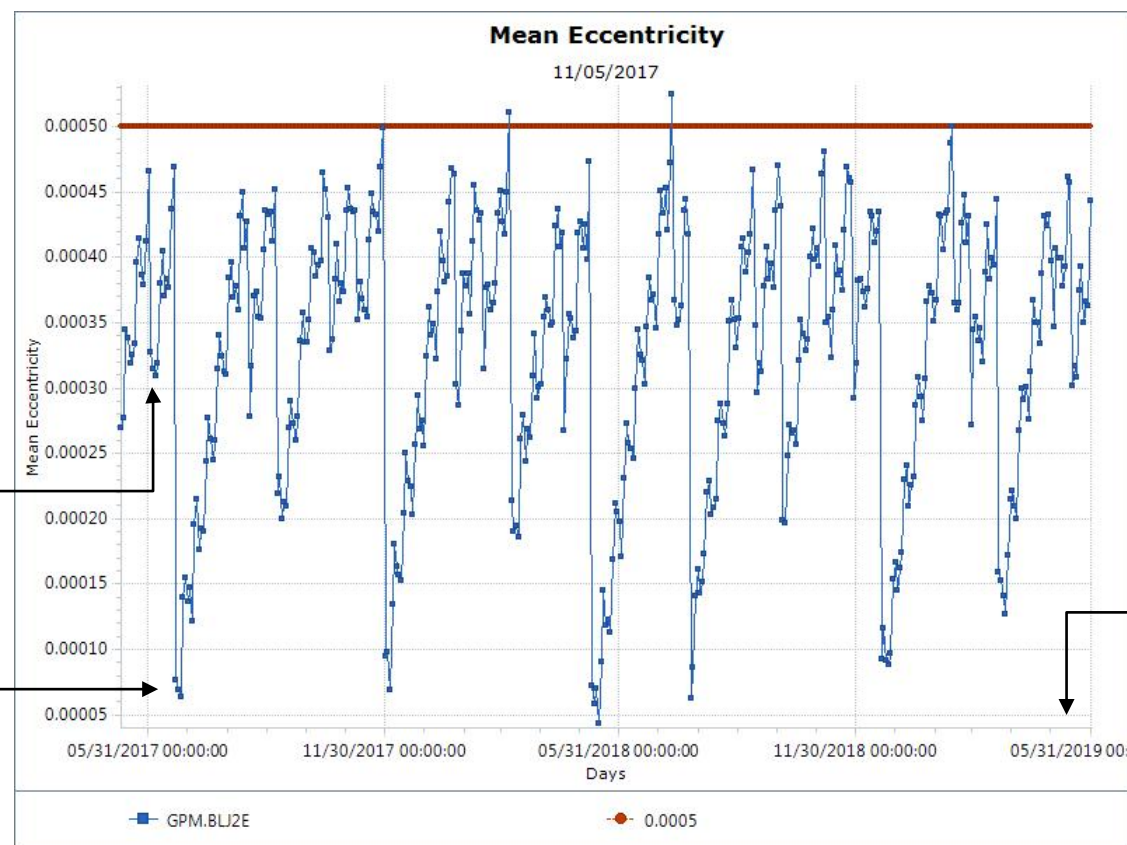
The retro pushes
the ECC down by a
small amount...



The retro pushes the ECC down by a small amount...and then the posigrade causes a large decrease.



The retro pushes the ECC down by a small amount, and then the posigrade causes a large decrease.



With the retrograde logic, the targeting scheme maintains the orbit well into the solar minimum.



- **The lifetime analysis script now had an implemented maneuver scheme that could successfully target and maintain orbit requirements over the full lifetime**

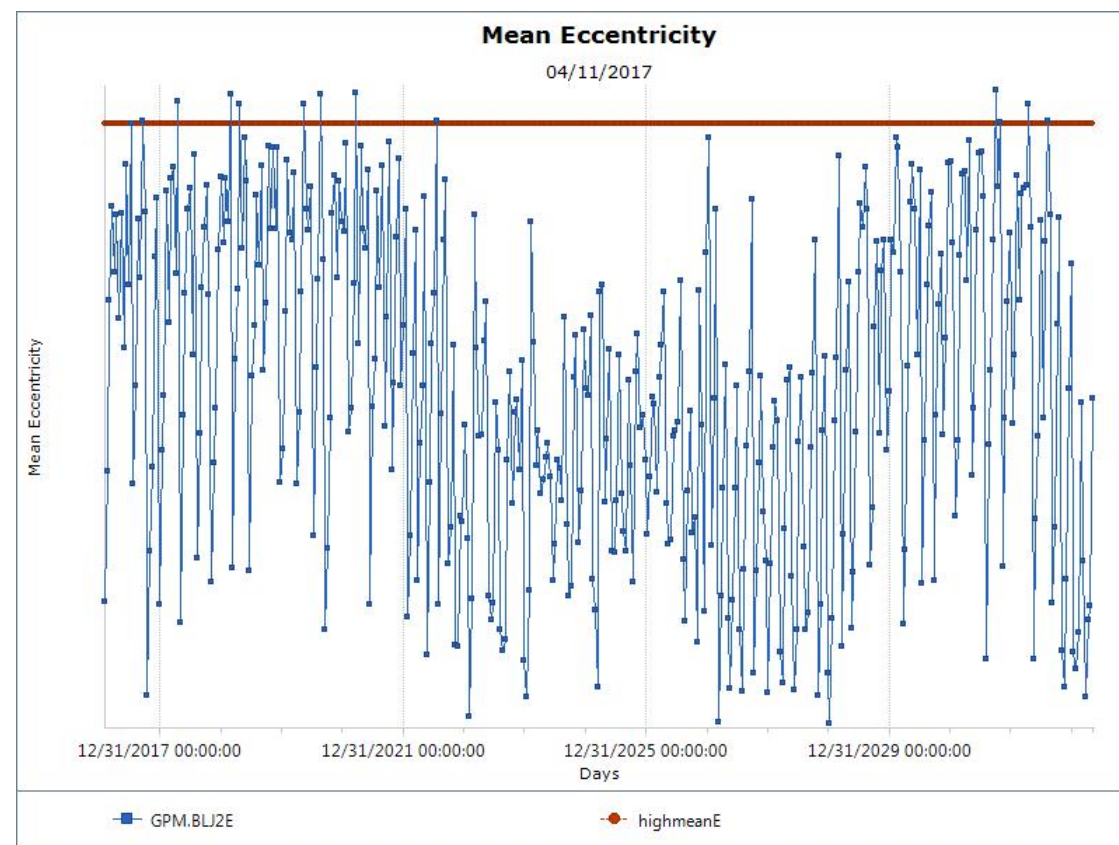
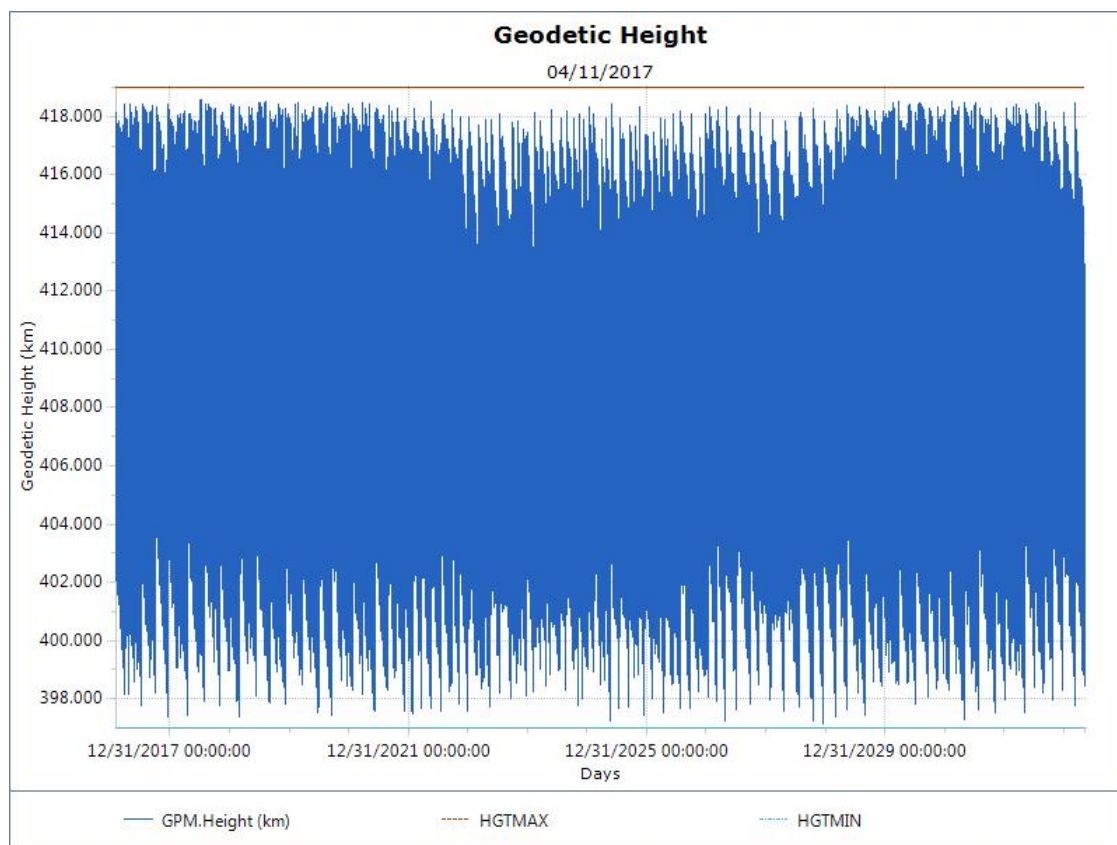


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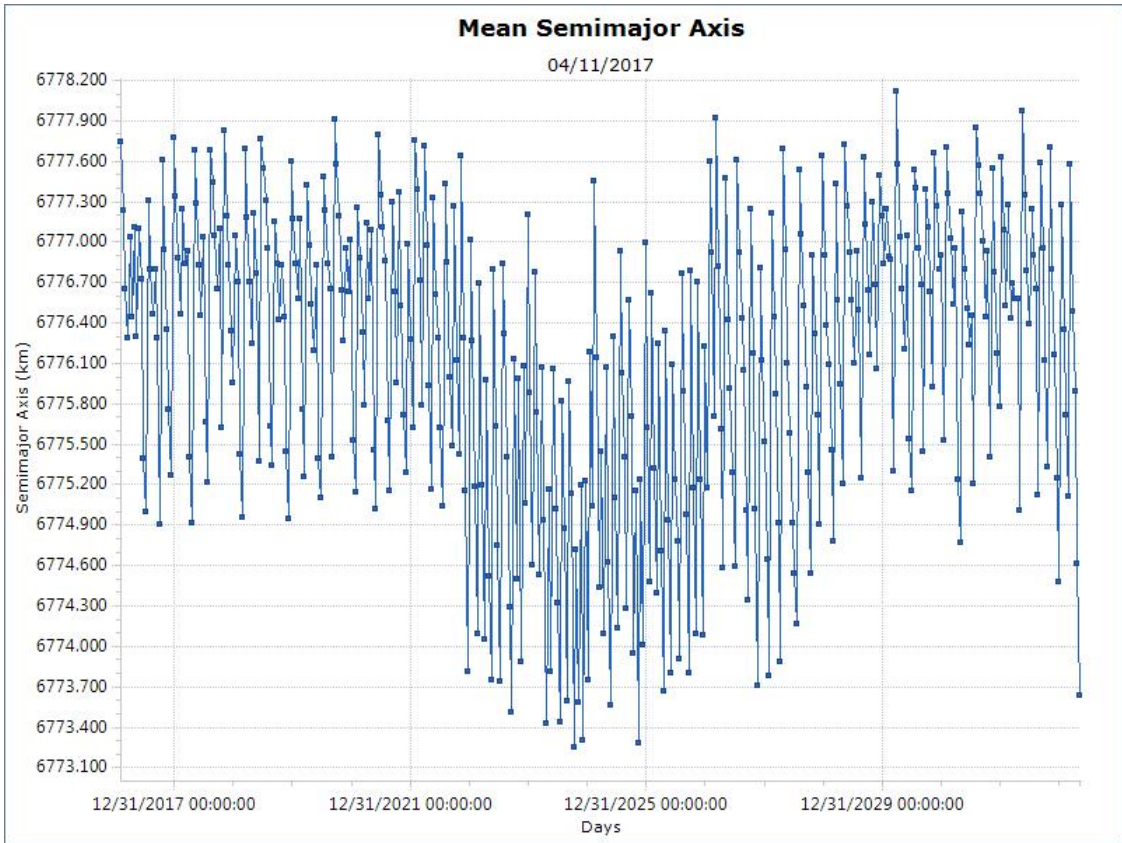


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- **Further, the scheme did not rely on any use of the “Profile G” SA configuration, thus alleviating concerns associated with gimbal cycling**
- **The top-level result, using the April 2017 Schatten model, was an end of mission life in mid-2033**

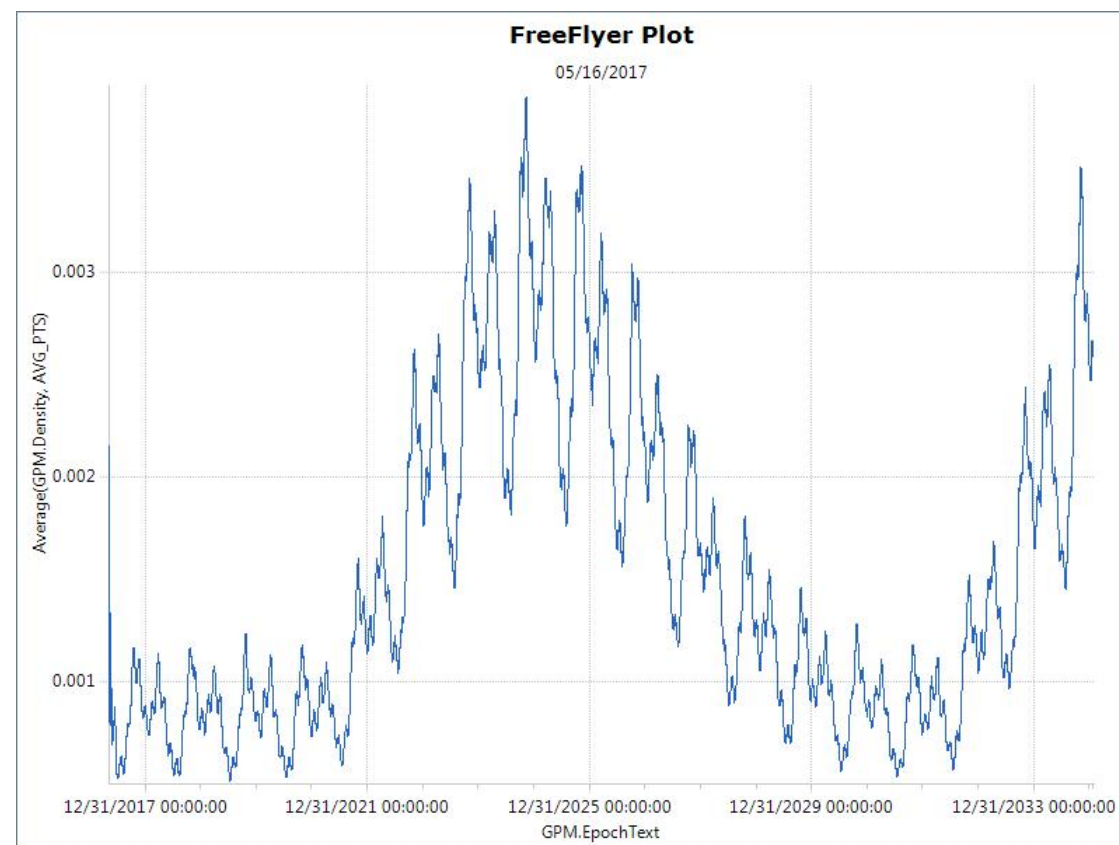
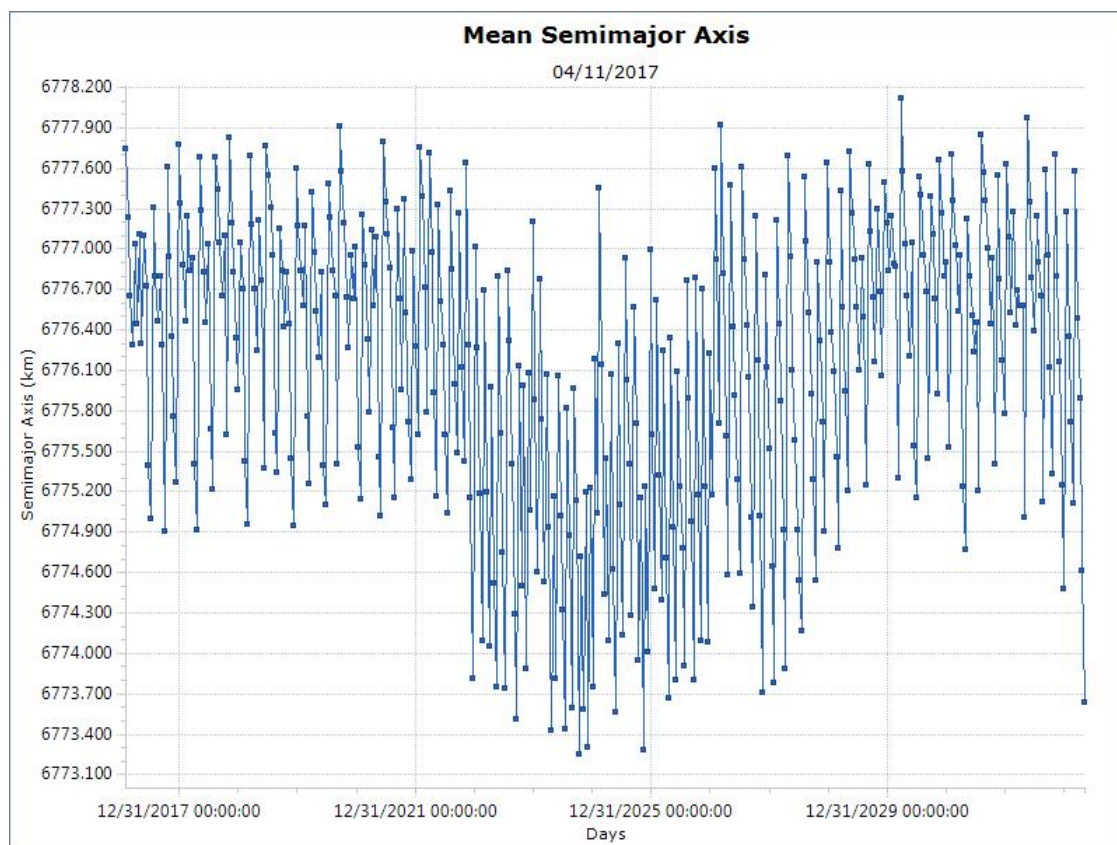
HGT and ECC evolution over GPM lifetime, with retro burns during solar minimum



SMA evolution...



SMA evolution...with GPM pulled lower in its control box during solar maximum





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- **GPM leverages a fixed 25-sec retro burn to achieve a nominal turnaround to the follow-up posigrade burn**
- **The overall minimal impact was non-intuitive, but was demonstrated with comprehensive fuel usage analysis**